Lizardtech DjVu Reference

DjVu v3

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1 Introduction

Although the Internet has given us a worldwide infrastructure on which to build the universal library, much of the world knowledge, history, and literature is still trapped on paper in the basements of the world's traditional libraries. Many libraries and content owners are in the process of digitizing their collections. While many such efforts involve the painstaking process of converting paper documents to computer-friendly form, such as SGML based formats, the high cost of such conversions limits their extent. Scanning documents and distributing the resulting images electronically is not only considerably cheaper, but also more faithful to the original document because it preserves its visual aspect.

Despite the quickly improving speed of network connections and computers, the number of scanned document images accessible on the Web today is relatively small. There are several reasons for this.

The first reason is the relatively high cost of scanning anything else but unbound sheets in black and white. This problem is slowly going away with the appearance of fast and low-cost color scanners with sheet feeders.

The second reason is that long-established image compression standards and file formats have proved inadequate for distributing scanned documents at high resolution, particularly color documents. Not only are the file sizes and download times impractical, the decoding and rendering times are also prohibitive. A typical magazine page scanned in color at 100 dpi in JPEG would typically occupy 100 KB to 200 KB, but the text would be hardly readable: insufficient for screen viewing and totally unacceptable for printing. The same page at 300 dpi would have sufficient quality for viewing and printing, but the file size would be 300 KB to 1000 KB at best, which is impractical for remote access. Another major problem is that a fully decoded 300 dpi color images of a letter-size page occupies 24 MB of memory and easily causes disk swapping.

The third reason is that digital documents are more than just a collection of individual page images. Pages in a scanned document have a natural serial order. Special provision must be made to ensure that flipping pages be instantaneous and effortless so as to maintain a good user experience. Even more important, most existing document formats force users to download the entire document first before displaying a chosen page. However, users often want to jump to individual pages of the document without waiting for the entire document to download. Efficient browsing requires efficient random page access, fast sequential page flipping, and quick rendering. This can be achieved with a combination of advanced compression, pre-fetching, pre-decoding, caching, and progressive rendering. DjVu decomposes each page into multiple components (text,

backgrounds, images, libraries of common shapes...) that may be shared by several pages and downloaded on demand. This allows a suitably designed DjVu-viewing application to to handle on-demand downloading, pre-fetching, decoding, caching, and progressive rendering of the page images.

2 Document Organization

This document describes the DjVu File Format. It is written "from top down" providing first a high-level understanding of the features and techniques used in DjVu (see *Overview*), then a mid-level view at the IFF85 level (see *Component pieces*), and finally a very detailed decription of the underlying algorithms and and byte-by-byte makeup of DjVu files (see *Low-level chunk structure* and the Appendices).

3 Overview

This section describes the DjVu file format at a high level: how DjVu uses the Mixed Raster Content model, how images are composed into documents and the non-raster data that such documents can also contain.

3.1 DjVu Images

The principal imaging model used in DjVu is the "Mixed Raster Content" (MRC) model described in ITU-T Recommendation T.44, ISO/IEC 16485. In this model, an image is decomposed into foreground and background layers. To select whether a particular pixel comes from the foreground or background a bitonal "selection" or "mask" layer is provided. These three layers are compressed separately using techniques which are optimized for each type of data.

The foreground and background layers are compressed using a wavelete-based continous-tone image compression technique known as IW44.

The mask layer is compressed using a bitonal image compression technique that takes advantage of repetitions of nearly identical shapes on the page (such as characters) to efficiently compress text images.

A DjVu image need not contain all three layers and alternative compression techniques are available for each layer.

3.2 DjVu Documents

DjVu Documents can be single- or multi-page. Each page consists of a DjVu image as described above (photo, bitonal or an MRC-based composition). Such a page, by itself is a valid DjVu Document. Multipage Documents can take either of two forms: Bundled or Indirect.

3.2.1 Bundled multi-page documents

Bundled multi-page DjVu document uses a single file to represent the entire document. This single file contains all the pages as well as ancillary information (e.g. the page directory, data shared by several pages, thumbnails, etc.). Using a single file format is very convenient for storing documents or for sending email attachments.

3.2.2 Indirect multi-page documents

There are problems inherent to storing multiple pages in a single file. A viewer may not be able to utilize a byte-serving mechanism such that that available in HTTP1.1. Therefore any request for any page of such a file will necessarily result in the entire document being transmitted. Furthermore, a reasonable work pattern is to read the first few pages (perhaps a Table of Contents) and then navigate to a page much further into the document. However, in such a file, data for page 100 can not be viewed until after data for pages 1-99 have been downloaded.

Indirect multipage documents address these problems. Such a document is composed of several files. The main file is named the index file. You can view document using the URL of the index file, just like you do with a bundled multi-page document. However, the index file is very small. It simply contains the document directory and the URLs of secondary files containing the page data. When you view an indirect multi-page document, the viewer only needs to download the files corresponding to the pages you are viewing.

3.3 Non-raster Data

3.3.1 Annotations

Every DjVu image optionally includes several different kinds of annotations. These annotations are often used to define hyper-links to other document pages or to arbitrary web pages. They can also be used for other purposes such as setting the initial viewing mode of a page and defining highlighted zones.

3.3.2 Hidden text

Every DjVu image optionally includes a hidden text layer that associated graphical features with the corresponding text. The hidden text layer is usually generated by running Optical Character Recognition software. This textual information provides for indexing DjVu documents and copying/pasting text from DjVu page images.

3.3.3 Thumbnails

DjVu documents sometimes contain pre-computed page thumbnails. These allow a viewer to display a graphical representation of many pages by downloading a very small "thumbnail" file instead of the actual pages themselves.

4 What's new in DjVu File Format

Since the last update to the file format documentation, Reference 1, the file format has been extended to include

- Multipage formats. DjVu documents can span more than one page. There are two multipage formats available: bundled (single file) and indirect (separate files for each page; see *DjVu Documents* and *Multipage Documents*)

- Annotations. Both initial viewing parameters (background color, initial zoom) and overlayed annotations (hyperlinks, text boxes) can be specified either at the document level ("shared") or at the page level. See *Annotation Chunk.*
- Hidden Text. Text and the associated layout information can be stored as with each image. This allows documents to be searched and indexed. See *Text Chunk.*
- Document Outline. A heirarchical outline can be specified at the document level. This allows the document to contain present an integrated outline for overview and navigation. See *Document Outline Chunk.*
- Colorized JB2. A palettized extension is provided for the bitonal encoder. See *Foreground Color JB2 Chunk.*

5 Acknowledgements

This work is significantly based on Reference 1 and the summary of file format changes described in the DjVuLibre project maintained by Leon Bottou and others.

6 References

6.1 DjVu 2

The DjVu File Format specification that was originally released by AT&T in 1999. http://www.djvuzone.org/djvu/djvu/djvuspec/001.djvu

6.2 IFF

EA IFF 85 format, Electronic Arts' public domain IFF standard for Interchange File

Format, released in January, 1985.

http://www.dcs.ed.ac.uk/home/mxr/gfx/2d/IFF.txt

6.3 JPEG

JPEG File Interchange Format, Version 1.02 (ISO DIS 10918-1, JPEG JFIF). The specification is located at http://www.w3.org/Graphics/JPEG/jfif.txt.

6.4 Tiff

http://partners.adobe.com/public/developer/en/tiff/TIFF6.pdf.

6.5 G4

ITU-T (CCITT) T.6. Facsimile Coding Schemes and Coding Control Functions for Group 4 Facsimile Apparatus

6.6 UTF8

All text in DjVu files is Unicode encoded using the UTF8 encoding.

http://www.unicode.org/versions/Unicode4.0.0/ch03.pdf

6.7 DjVuLibre

An open source reference implementation of this file format specification is available at http://sourceforge.net/projects/djvu/. Throughout this specification, there are numerous references to source files in this implementation.

7 Component pieces (IFF chunks) of DjVu documents and images

This section describes the DjVu file format at a middle level. This includes types of chunks which can go into various types of documents but not a detailed layout of the contents of those chunks.

DjVu documents are IFF85 files (see reference 2 for details). The IFF85 structure provides a hierarchy of containers which hold various types of information in a DjVu file. The containers are called "chunks." How the chunk is used (what it holds) can be determined by its "chunk type" or "chunk id." For example, the list of files contained in a multipage document is held in the "DIRM" ("directory") chunk, annotations are held in a "ANTz" chunk.

"FORM" chunks are composite (contain other chunks). Their specific use is exposed by a secondary chunk ID. For example a single page consists of several different chunks all contained within a single "FORM:DJVU" chunk. A multipage document consists of several pages (and other chunks) all contained in a "FORM:DJVM" chunk.

This section discusses the various kinds of DjVu documents and the corresponding chunks of which they consist.

7.1 Single Page Documents

A Single Page Document is composed of a single "FORM:DJVU" composite chunk. This composite chunk always begins with one "INFO" chunk describing the image size, resolution and related information (see *Document Info Chunk*). The document containts exactly one DjVu Image whose content varies as described below.

7.1.1 Photo DjVu Image

Photo DjVu Image files are best used for encoding photographic images in colors or in shades of gray. The data compression model relies on the IW44 wavelet representation. This format is designed such that the IW44 decoder is able to quickly perform progressive rendering of any image segment using only a small amount of memory. One or more additional "BG44" chunks contain the image data encoded with the IW44 representation. The image size specified in the "INFO" chunk and the image size specified in the IW44 data must be equal.

7.1.2 Bi-level DjVu Image

Bilevel DjVu Image files are used to compress black and white images representing text and simple drawings. The JB2 data compression model uses the soft pattern matching technique, which essentially consists of encoding each character by describing how it

differs from a well-chosen already-encoded character. A "Sjbz" chunk contains the bilevel data encoded with the JB2 representation (see appendix 2). The image size specified in the "INFO" chunk and the image size specified in the JB2 data must be equal.

7.1.3 Compound DjVu Image

Compound DjVu Files are an extremely efficient way to compress high resolution Compound document images containing both pictures and text, such as a page of a magazine. Compound DjVu Files represent the document images using two layers. The *background layer* is used for encoding the pictures and the paper texture.

The *foreground layer* is used for encoding the text and the drawings. Additional chunks hold the components of either the foreground or the background layers.

The main component of the foreground layer is a bilevel image named the *foreground mask*. The pixel size of the foreground mask is equal to the size of the DjVu image. It contains a black-on-white representation of the text and the drawings. This image is encoded by a "Sjbz" chunk using the JB2 representation. There may also be a companion chunk "Djbz" containing a *shape dictionary* that defines bilevel shapes referenced by the "Sjbz" chunk.

7.1.3.1 Foreground Encoding

The foreground colors can be encoded according to two models:

The foreground colors may be encoded using a small color image, the *foreground color image*, encoded as a single "FG44" chunk using the IW44 representation (see IW44Image.h). Such compound DjVu images are rendered by painting the foreground color image on top of the background color image using the foreground mask as a stencil. The pixel size of the foreground color image is computed by rounding up the quotient of the mask size by an integer sub-sampling factor ranging from 1 to 12. Most Compound DjVu Images use a foreground color sub-sampling factor of 12. Smaller sub-sampling factors produce very slightly better images.

The foreground colors may be encoded by specifying one solid color per object described by the JB2 encoded mask. These *JB2 colors* are color-quantized and stored in a single "FGbz" chunk (see section 6.3.10). Such compound DjVu images are rendered by painting each foreground object on top of the background color image using the solid color specified by the "FGbz" chunk.

7.1.3.2 Background Encoding

The background layer is a color image, *the background color image* encoded by an arbitrary number of "BG44" chunks containing successive IW44 refinements (see appendix 1). The size of this image is computed by rounding up the quotient of the mask size by an integer sub-sampling factor ranging from 1 to 12. Most Compound DjVu Images use a background sub-sampling factor equal to 3. Smaller sub-sampling factors are adequate for images with a very rich paper texture. Larger sub-sampling factors are adequate for images containing no pictures.

There are no ordering or interleaving constraints on these chunks except that (a) the "INFO" chunk must appear first, and (b) the successive "BG44" refinements must appear with their natural order. The chunk order simply affects the progressive rendering of DjVu images on a web browser.

7.1.3.3 Alternative encodings

Besides the JB2 and IW44 encoding schemes, the DjVu format supports alternative encoding methods for its components.

The foreground mask may be represented by a single "Smmr" chunk instead of "Sjbz". The "Smmr" chunk contains a bilevel image encoded with the Fax-G4/MMR method. Although the resulting files are typically six times larger, this capability can be useful when DjVu is used as a front-end for fax machines and scanners with embedded Fax-G4/MMR capabilities.

The background color image may be represented by a single "BGjp" chunk instead of several "BG44" chunks. The "BGjp" chunk contains a JPEG encoded color image (see JPEGDecoder.cpp). The resulting files are significantly larger and lack the progressivity of the usual DjVu files. This is useful because some scanners have embedded JPEG capabilities.

The foreground color image may be represented by a single "FGjp" chunk instead of a single "FG44" chunk. This is useful because some scanners have embedded JPEG capabilities.

7.1.3.4 Annotations and Textual Information

All types of DjVu images may contain annotation chunks. Annotation chunks are used to describe hyperlinks, to specify more viewer settings (page background, initial zoom, etc), and to hold metadata information. Annotations are contained in "ANTa" or "ANTz" chunks.

All types of DjVu image files may also contain a computer readable description of the text appearing on the page. This information is contained by either a "TXTa" chunk or "TXTz" chunk.

7.2 Multipage Documents

A multipage document is composed of a "FORM:DJVM" whose first chunk is a "DIRM" chunk containing the *document directory*. This directory lists all component files composing the given document, helps to access every component file and identify the pages of the document.

In a *bundled* multipage file, the component files are stored immediately after the "DIRM" chunk, within the "FORM:DJVM" composite chunk.

In an *indirect* multipage file, the component files are stored in different files whose URLs are composed using information stored in the "DIRM" chunk.

7.2.1 Component files

A multipage DjVu document necessarily references other FORM (composite) chunks. Specifically

- Each page is single page document (FORM:DJVU chunk).
- Embedded thumbnails (if any) are contained in one or more FORM:THUM chunks
- Shared annotations (if any) and shape dictionaries (if any) are contained in one or more FORM:DJVI chunks.

Each of these composite chunks (FORM:DJVU, FORM:THUM, FORM:DJVI) is a well-formed IFF bytestream in its own right and can be held in a separate disk file. In the context of a multipage – either bundled or indirect – document, we refer to these composite chunks as *component files*.

7.2.2 Including shared information

In many cases, efficiencies can be achieved by sharing JB2 shape definitions and/or annotations across pages. To facilitate this, any DjVu image file contained in a multipage file may contain an "INCL" chunk containing the ID of a shared component file. The decoder processes the chunks contained in the shared component file as if the DjVu image file contained them. All relevant pages include this shared component file. Although they appear in several pages, these shared shapes are encoded only once in the document.

A shared component file is composed of a single "FORM:DJVI" potentially containing any information otherwise allowed in a DjVu image file (except for the "INFO" chunk of course).

8 Low-level chunk structure and definition

This section describes the DjVu file format at a low level. This includes the binary layout of the IFF85 wrapper and, of course, the layout of each contained chunk.

8.1 Header

The first four bytes of a DjVu file are 0x41 0x54 0x26 0x54. This preamble is not part of the EA IFF 85 format, but it is required in order to identify DjVu files.

8.2 DjVu File structure

8.2.1 IFF Wrapper

An IFF file consists of a number of chunks. Each chunk is laid out in 3 fields:

BYTE*4	Chunk ID. Describes the use of the chunk. The strings that identify the types of chunks used in DjVu are listed below.
INT32	Length (MSB first). The length of the Data

BYTE[length]	The data to be contained.

A chunk whose type is not recognized by the application is to be ignored. In the IFF format, chunks may be nested: a chunk may contain other chunks as part of its data. In the DjVu format, there is only one chunk at the outermost nesting level, a FORM chunk. All other chunks appear within the FORM chunk, sequentially, with no nesting.

Each chunk, including those nested within another chunk, must begin on an even byte boundary; that is, the number of bytes in the file before the beginning of the chunk must be an even integer. If necessary to ensure that a chunk begins on a even byte boundary, a single padding byte whose value is 0x00 is placed before a chunk.

Example:

0000000: 41 54 26 54 AT&T; magic described in 8.1

0000004: 46 4f 52 4d FORM; chunkID = FORM

0000008: 00 00 68 a6 ..h¦ ; (0xA668 = 26790, length of this FORM chunk)

000000b: 444a 5655 DJVU ; first four bytes of contained data. Since this is a a FORM chunk , this starts with the subidentifier. This is a FORM:DJVU chunk, a single page document.

8.2.2 Chunk Summary

The chunks used in the DjVu file format are summarized in Table 1.

Table 1. Chunk Summary

Chunk ID	Usage
FORM	The composite chunk. The first four data bytes of the FORM chunk are a secondary identifier. Such chunks are referred to as FORM:*XXXX* where "*XXXX*" stands for the secondary identifier.
FORM:DJVM	A multipage DjVu document. Composite chunk that contains the DIRM chunk, possibly shared/included chunks and subsequent FORM:DJVU chunks which make up a multipage document
FORM:DJVU	A DjVu Page / single page DjVu document. Composite chunk that contains the chunks which make up a page in a djvu document
FORM:DJVI	A "shared" DjVu file which is included via the INCL chunk. Shared annotations, shared shape dictionary.
FORM:THUM	Composite chunk that contains the TH44 chunks which are the embedded thumbnails
DIRM	Page name information for multi-page documents
NAVM	Bookmark information
ANTa, ANTz	Annotations including both initial view settings and overlaid hyperlinks, text boxes, etc.
TXTa, TXTz	Unicode Text and layout information

Djbz	Shared shape table.
Sjbz	BZZ compressed JB2 bitonal data used to store mask.
FG44	IW44 data used to store foreground
BG44	IW44 data used to store background
TH44	IW44 data used to store embedded thumbnail images
WMRM	JB2 data required to remove a watermark
FGbz	Color JB2 data. Provides a color for each (blit or shape?) in the corresponding Sjbz chunk.
INFO	Information about the a DjVu page
INCL	The ID of an included FORM:DJVI chunk.
BGjp	JPEG encoded background
FGjp	JPEG encoded foreground
Smmr	G4 encoded mask

Each chunk is described in detail in the following section

8.3 IFF Chunk Types

8.3.1 Container Chunk: FORM

The FORM chunk is used as a chunk container. The first four bytes of the FORM chunk are a secondary ID used to identify the chunks being contained.

8.3.1.1 FORM:DJVM

As discussed in Multipage Documents, a multipage DjVu Document is contained a single (composite) FORM:DJVM chunk. The first nested chunk is always a "DIRM" chunk containing the document directory (see DjVmDir.h) which represents the list of the component files that make up the document. An optional "NAVM" chunk, which describes the outline of the document, may follow the "DIRM" chunk.

Example

```
FORM:DJVM [126475]
  DIRM [59]       Document directory (bundled, 3 files 2 pages)
  FORM:DJVI [3493] {dict0002.iff}
  FORM:DJVU [115016] {p0001.djvu}
  FORM:DJVU [7869] {p0002.djvu}
```

8.3.1.2 FORM:DJVU

As discussed in Single Page Documents, a single page in a DjVu is contained in a single (composite) FORM:DJVU chunk. The nested first chunk must be the INFO chunk. The chunks after the INFO chunk may occur in any order, although the order of the BG44 chunks, if there is more than one, is significant.

Example:
```
 FORM:DJVU [26790]
   INFO [10]       DjVu 2202x967, v26, 300 dpi, gamma=2.2
   Sjbz [13133]    JB2 bilevel data
   FG44 [185]      IW4 data #1, 76 slices, v1.2 (color), 184x81
   BG44 [935]      IW4 data #1, 74 slices, v1.2 (color), 734x323
   BG44 [1672]     IW4 data #2, 10 slices
   BG44 [815]      IW4 data #3, 4 slices
   BG44 [9976]     IW4 data #4, 9 slices
```

8.3.1.3 FORM:DJVI

Multipage DjVu files can share information between pages by nesting a chunk inside a FORM:DjVi chunk (which is itself held inside the FORM:DjVm chunk) and referencing the contained chunk from within a page. Individual pages reference the shared chunks via the INCL chunk.

Example:
```
 FORM:DJVM [126475]
   DIRM [59]       Document directory (bundled, 3 files 2 pages)
   FORM:DJVI [3493] {dict0002.iff}
     Djbz [3481]     JB2 shared dictionary
   FORM:DJVU [115016] {p0001.djvu}
     INFO [10]       DjVu 2539x3295, v25, 300 dpi, gamma=2.2
     INCL [12]       Indirection chunk --> {dict0002.iff}
     Sjbz [70497]    JB2 bilevel data
...
```

8.3.1.4 FORM:THUM

Pre-rendered Thumbnails may be included. This allows very large documents to render thumbnails of pages without downloading and decoding them. FORM:THUM chunks contain several TH44 chunks. Each of these chunks contains the thumbnails of the pages that follow.

Example:
```
 FORM:DJVM [2272012]
   DIRM [108]      Document directory (bundled, 7 files 4 pages)
   FORM:THUM [5960] {p0001.thumb}
     TH44 [5948]     Thumbnail icon for page 1
   FORM:DJVU [1413380] {p0001.djvu}
     INFO [10]       DjVu 4728x6300, v25, 600 dpi, gamma=2.2
...
   FORM:THUM [12148] {p0004.thumb}
     TH44 [3418]     Thumbnail icon for page 2
     TH44 [4150]     Thumbnail icon for page 3
     TH44 [4552]     Thumbnail icon for page 4
   FORM:DJVU [777858] {p0002.djvu}
```

...

8.3.2 Directory Chunk: DIRM

As described in Multipage Documents, a multipage document will contain "component files" such as individual pages (FORM:DJVU) or shared annotations (FORM:DJVI).

The first contained chunk in a FORM:DJVM composite chunk is the DIRM chunk containing the *document directory*. It contains information the decoder will need to access the component files (see *Multipage Documents*).

8.3.2.1 Unencoded data

The first part of the "DIRM" chunk consists is unencoded:

Byte	Flags/Version	$b_7b_6\ldots b_0$ b_7 (MSB) is the *bundled* flag. 1 for bundled, 0 for indirect $b_6\ldots b_0$ is the version. Currently 1.
INT16	nFiles	Number of component files
INT32	Offset0, Offset1, Offset2..	When the document is a bundled document (i.e. the flag *bundled* is set), the header above is followed by the offsets of each of the component files within the "FORM:DJVM". These offsets allow for random component file access. These may be omitted for indirect documents. When the document is indirect, these offsets are omitted.

8.3.2.2 BZZ encoded data

The rest of the chunk is entirely compressed with the BZZ general purpose compressor. We describe now the data fed into (or retrieved from) the BZZ codec (see BSByteStream.cpp and appendix 4)

INT24	Size0, size1, size2, …	Size of each component file. May be 0 for indirect documents.
BYTE	Flag0, flag1, flag2	Flag byte for each component file 0b<hasname><hastitle>000000 for a file included by other files. 0b<hasname><hastitle>000001 for a file representing a page. 0b<hasname><hastitle>000010 for a file containing thumbnails. Flag *hasname* is set when the name of the file is different from the file ID. Flag *hastitle* is set when the title of the file is different from the file ID. These flags are used to avoid encoding the same string three times. Note: In practice, the *hasname* and *hastitle* bits are poorly tested and not used.

ZSTR	ID0, Name0, Title0, ID1, Name1, Title1, …	There are one to three zero-terminated strings per component file. The first string contains the ID of the component file. If *hasname* is set then there is a second string which contains the name of the component file (in the case of an indirect file, this is the disk filename). If *hastitle* is set, then there is a third string which contains the name of the component (for display … for example alternate page numberings in the Forward, or Preface). Note: ID0 in practice, ID0 is the only string used and in the case of indirect files, is the same as the disk filename of the component file.

Examples

3 Page bundled file with a shared dictionary

RAW: 81 3 54 e02 1cf52 (BZZ Decoded:) dad 1c150 1ec5 0 1 1 64 69 63 74 30 30 30 32 dict0002.iff 2e 69 66 66 0 70 30 30 30 31 2e 64 6a 76 75 0 p0001.djvu 70 30 30 30 32 2e 64 6a 76 75 0 p0002.djvu	*Flags/Version*: bundled, version 1 *nFiles*: 3 *Offsets*: 0x54, 0xE02, 0x1CF52 *Sizes*: 0xDAD, 0x1C150, 0x1EC5 *Flags*: 0, 1, 1 *ZStr*: 3 null terminated filenames as shown.

3 Page indirect file with a shared dictionary

RAW: 1 3 (BZZ Decoded:) dad 1c150 1ec5 0 1 1 64 69 63 74 30 30 30 32 dict0002.iff 2e 69 66 66 0 70 30 30 30 31 2e 64 6a 76 75 0 p0001.djvu 70 30 30 30 32 2e 64 6a 76 75 0 p0002.djvu	*Flags/Version*: indirect, version 1 *nFiles*: 3 *Offsets*: omitted for indirect files *Sizes*: 0xDAD, 0x1C150, 0x1EC5 *Flags*: 0, 1, 1 *ZStr*: 3 null terminated filenames as shown.

8.3.3 Document Outline Chunk: NAVM

The NAVM chunk contains bookmarks which describe an outline of the document. The intent is to allow content authors to create an electronic Table of Contents which gives users rapid access to various parts of the document.

This chunk is optional; but if present, must immediately follow the DIRM chunk.

The entire chunk is BZZ encoded and starts with a single field specifying the total number bookmark records

UINT16	countBookmarks	The total number of bookmarks in the document

And then the individual bookmark records, nested as necessary.

BYTE	nChildren	The number of immediate child bookmark records

INT24	nDesc	size of description text
UTF8	sDesc	the description text.
INT24	nURL	Size of the URL text
UTF8	sURL	the URL text. This may (and typically does) use the syntax described for the URLs in the Annotation chunk (and similarly, is not URL-encoded)

Example (as passed to BZZ codec).

Consider a small document outline as follows:

Table of Contents

Introduction

Datasheet

For More Info (Online)

There is no hyperlink associated with the single root entry "Table of Contents". At a binary level, the chunk looks like this:

0x0012F06C 00 04 02 00 .... 0x0012F070 00 11 54 61 ..Ta	countBookmarks = 4; nChildren = 2; nDesc=17
0x0012F074 62 6c 65 20 ble 0x0012F078 6f 66 20 43 of C 0x0012F07C 6f 6e 74 65 onte 0x0012F080 6e 74 73 00 nts.	sDesc: "Table of Contents"
0x0012F084 00 00 00 00 .... 0x0012F088 00 0c 49 6e ..In	nURL=0; sURL omitted; nChildren=0; nDesc=12
0x0012F08C 74 72 6f 64 trod 0x0012F090 75 63 74 69 ucti 0x0012F094 6f 6e 00 00 on..	sDesc: "Introduction"
0x0012F098 0b 23 70 30 .#p0 0x0012F09C 30 30 31 2e 001. 0x0012F0A0 64 6a 76 75 djvu	nURL=11; sURL = "#p0001.djvu";
0x0012F0A4 01 00 00 09	nChildren=1; nDesc=9
0x0012F0A8 44 61 74 61 Data 0x0012F0AC 73 68 65 65 shee 0x0012F0B0 74 00 00 0b t...	sDesc="Datasheet" nURL=11
0x0012F0B4 23 70 30 30 #p00 0x0012F0B8 30 32 2e 64 02.d 0x0012F0BC 6a 76 75 00 jvu.	sURL="p0002.djvu" nChildren=0
0x0012F0C0 00 00 16 46 ...F	nDesc=22
0x0012F0C4 6f 72 20 4d or M	sDesc="For More Info (Online)"

0x0012F0C8 6f 72 65 20 ore 0x0012F0CC 49 6e 66 6f Info 0x0012F0D0 20 28 4f 6e (On 0x0012F0D4 6c 69 6e 65 line 0x0012F0D8 29 00 00 19)...	nURL=25
0x0012F0DC 68 74 74 70 http 0x0012F0E0 3a 2f 2f 77 ://w 0x0012F0E4 77 77 2e 6c ww.l 0x0012F0E8 69 7a 61 72 izar 0x0012F0EC 64 74 65 63 dtec 0x0012F0F0 68 2e 63 6f h.co 0x0012F0F4 6d cc cc cc mÌÌÌ	sDesc="http://www.lizardtech.com"

8.3.4 Annotation Chunk: ANTa, ANTz

Annotations are contained in "ANTa" or "ANTz" chunks. The "ANTa" chunks contain the annotation in plain text. The "ANTz" chunks contain the same information compressed with the BZZ encoder (see BSByteStream.h).

The use of the ANTa chunk is discouraged.

Pages can share annotations using an INCL chunk as explained in section Including Shared Information. The complete annotation text is obtained by concatenating all annotation chunks present in the page. A restriction of the current reference library implementation limits the number of shared annotation files to one.

The syntax of the annotation text uses a simple parenthesized notation. All text is standard UTF8.

8.3.4.1 Initial Document View

8.3.4.1.1 Background Color.

(background *color*)

Specify the color of the viewer area surrounding the DjVu image. Colors are represented with the X11 hexadecimal syntax #RRGGBB. For instance, #000000 is black and #FFFFFF is white.

8.3.4.1.2 Initial Zoom

(zoom *zoomvalue*)

Specify the initial zoom factor of the image. Argument *zoomvalue* can be one of **stretch**, **one2one**, **width**, **page**, or composed of the letter d followed by a number in range 1 to 999 representing a zoom factor (such as in d300 or d150 for instance.)

8.3.4.1.3 Initial Display level

(mode *modevalue*)

Specify the initial display level of the image. Argument *modevalue* is one of **color**, **bw**, **fore**, or **black**.

8.3.4.1.4 Alignment

(align horzalign vertalign)

Specify how the image should be aligned on the viewer surface. By default the image is located in the center. Argument *horzalign* can be one of **left**, **center**, or **right**. Argument *vertalign* can be one of **top**, **center**, or **bottom**.

Example (Typical Shared Annotation)

(background #FFFFFF) (zoom page) (mode bw) (align center default)

8.3.4.2 Maparea (overprinted annotations)

(maparea *url comment area* ...)

A "Maparea annotation" defines an overprinted annotation (one that is drawn on top of the rendered image). These annotations are used to draw Lines, Text boxes, Highlight areas with optional hyperlinking capability. The *area* parameter distinguishes among several different forms of mapareas. For convenience, we will sometimes refer to "**rect** mapareas" when we mean "mapareas whose *area* attribute is **rect**" and similarly "**line** mapareas", etc.

A note about escape sequences. The only currently-accepted escape sequence is for a single quote: \". All other string characters are written in UTF8 (ascii-compatible). Specifically, where needed, spaces, ampersands ("&"), backslashes ("\") and parentheses ("(", ")") are written directly. Erroneous and unrecognized constructs are silently ignored.

8.3.4.2.1 url

Argument *url* takes either of these forms

href
(**url** *href target*)

href can be an arbitrary URL or can be composed of the hash character (#) followed by either a component file identifier or a page number. Page numbers may be prefixed with an optional sign to represent a page displacement. For instance the strings #-1 and #+1 can be used to access the previous page and the next page. *href* is not URL-encoded.

target is a string representing the target frame for the hyper-link, as defined by the HTML anchor tag <A>

8.3.4.2.2 comment

Argument *comment* is a string that might be displayed by the viewer when the user moves the mouse over the maparea.

8.3.4.2.3 area

Argument *area* defines the shape and the location of the maparea. The following forms are recognized:

(**rect** *xmin ymin width height*) // defines a rectangle
(**oval** *xmin ymin width height*) // defines an oval
(**text** *xmin ymin width height*) // defines a text box
(**poly** *x0 y0 x1 y1 ...*) // defines a polygon
(**line** *x0 y0 x1 y1*) // defines a line with optional arrow head

All parameters are numbers representing coordinates. Coordinates are measured in pixels and have their origin at the bottom left corner of the rotated (this for historical reasons; see *Document Info Chunk*) page.

8.3.4.2.3.1 Miscellaneous parameters

The remaining expressions in the maparea list concern the visual effects associated with the maprea annotation.

Summary (X denotes "supported")

Area attribute	**rect**	**oval**	**poly**	**line**	**text**
Miscellaneous parameter					
Border type					
(**none**)/(**xor**)/(**border** *color*)	X	X	X	X	X
(**shadow_*** *thickness)*	X				
(**border_avis**)	X	X	X		
(**hilite** *color*) / (**opacity** *op*)	X				
(**arrow**)/(**width** *w*) /(**lineclr** *c*)				X	
(**backclr** c) /(**textclr** c) /(**pushpin**)					X

8.3.4.2.3.1.1 Border type

A first set of options define the border-type of the associated maparea:

(**none**) // no border
(**xor**)
(**border** *color*) // solid border width 1
(**shadow_in** *thickness*)
(**shadow_out** *thickness*)
(**shadow_in** *thickness*)
(**shadow_out** *thickness*)

where parameter *color* has syntax #RRGGBB as described above, and parameter *thickness* is an integer in range 1 to 32 and specifies line thickness in pixels. The last four border modes are only supported for **rect** mapareas.

8.3.4.2.3.1.2 Border always visible

The border becomes visible when the user moves the mouse over the maparea. The border may be made always visible by using the "*border al*ways *vis*ible" option as follows:

(**border_avis**)

8.3.4.2.3.1.3 Highlight color and opacity

The following options may be used with **rect** mapareas. The complete area will be highlighted using the specified color at the specified opacity (0-100, default of 50).

(**hilite** *color*)
(**opacity** *op*)

8.3.4.2.3.1.4 Line and Text parameters

The following options may be used with **line** mapareas to specify an optional ending arrow, the line width and color:

(**arrow**) --- default (not present) means "no ending arrow"
(**width** *w*) --- default (not present) means *w* == 1
(**lineclr** *color*) --- default (not present) means *color*==black

The following options may be used with **text** mapareas:

(**backclr** *bkcolor*) --- default (not present) means transparent
(**textclr** *txtcolor*) --- default (not present) means black
(**pushpin**) --- not default (not present) means "not push pin"

If any border type non-"none" is specified, the border is drawn "solid", (as if "(color c)" were specified).

Where

bkcolor specifies the background text color

txtcolor specifies the text color

pushpin specifies that the text box is collapsible. This allows the text box to expand into view when needed but not obscure the image otherwise..

Examples (typical page-level annotation):

```
(maparea "http://www.lizardtech.com/" "Here is a rectangular hyperlink"
   (rect 543 2859 408 183 ) (xor ) )
(maparea "http://www.lizardtech.com/" "Here is an oval hyperlink"
   (oval 1068 2853 429 195 ) (xor )
 (maparea "" "Here is a text box"(text 1635 2775 423 216 )
   (pushpin ) (backclr #FFFF80 ) (border #000000 ) )
(maparea "" "Arrow" (line 591 3207 1512 3138 ) (arrow ) (none ) )
```

8.3.4.3 Printed headers and footers

User-specified strings may be added to printed output.

(<**phead** | **pfoot**> *position_string1*, *position_string2*, …)

Where position_string is of the form: <**left**|**center**|**right**>::<string>

Example

(phead "left::Sept 20, 2005" "right::Today's Menu ") (pfoot "center::Chez Dominique")

8.3.5 Text Chunk: TXTa, TXTz

Text is contained in "TXTa" or "TXTz" chunks. The "TXTa" chunks contain the text unencoded. The "ANTz" chunks contain the same information compressed with the BZZ encoder (see BSByteStream.h).

The use of the TXTa chunk is discouraged.

The chunk begins with the UTF8-encoded text of the page:

INT24	lenText	size of the text string in bytes
UTF8	strText	UTF8 encoded string
BYTE	Version	Version is currently 1

[Implemenation Note]. The text may optionally contain separators between text blocks corresponding to various zones. These may be simple CR/LF and <space>, terminating NULL, or the more arcane cases such as VT (vertical tab, ascii 0xB) GS (group separator, 0x1D), RS (record separator 0x1E) and US (unit separator 0x1F),. Such separators can have a significant impact on searching and exporting implementations. Decoding applications should be prepared to address this.

Following this is a list of 0 or more zones which define the bounding rectangles of the text above. Zones may contain heirachically smaller zones (e.g. columns contain regions, words contain characters) and zones at the same hierarchical level should not overlap. Zones are listed in reading order with parents preceeding children.

Each Zone is record is 17 bytes long and comprised of the following 8 fields.

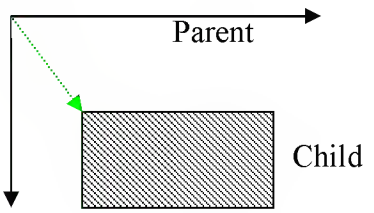
BYTE	Ztype	Zone Type (see below)
INT16	X	Unsigned two-byte integer. X component of the zone's offset from a preceeding zone. See below
INT16	Y	Unsigned two-byte integer. Y component of the zone's offset from a preceeding zone. See below
INT16	Width	Unsigned two-byte integer. Width of the zone, offset by 32768.
INT16	Height	Unsigned two-byte integer. Height of the zone, offset by 32768.
INT16	offText	Not used. Must be 0.
INT24	lenText	Text length. The number of characters n this zone.
INT24	nChildren	Number of child zones

Zone Type can be any of Page (1), Column (2), Region (3), Paragraph (4), Line (5), Word (6), Character (7).

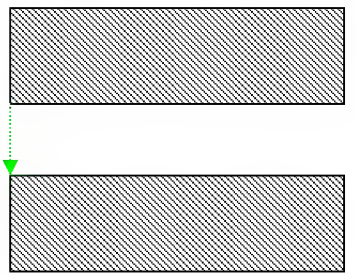
X, y width and height are sixteen bit unsigned integers which encode a potentially negative value by adding an offset of 32768 (0x8000). To recover the actual value subtract 0x8000. Coordinates are unrotated (see *Document Info Chunk*).

X and Y identify the zone's displacement from either the zone's preceeding sibling (if any) or the zone's parent. Depending on the context, the coordinate system and the portion of the zone being located vary. There are three cases to consider:

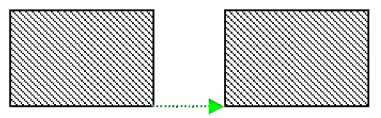
- The zone is the first contained zone of a parent (e.g. the first Word in a Line). In such a case, we measure from the parent's upper left corner to the zone's upper left corner. X to right and Y down.



- The zone is the second or subsequent Page, Paragraph or a Line contained in a parent (e.g. second Line in a Paragraph). In such a case, we again measure from the previous Lower Left corner to the zone's upper left. X to the right and Y down.



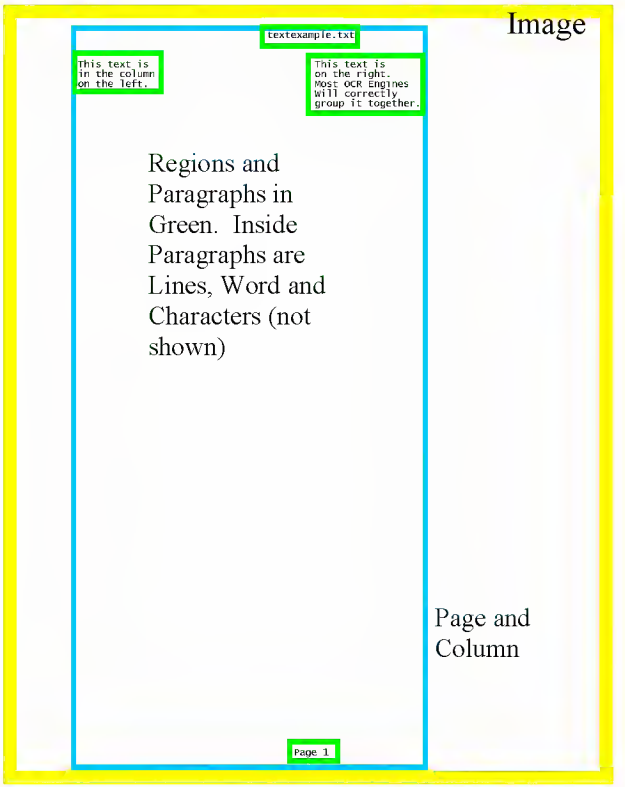
- The zone is the second or subsequent Column, Word or Character contained in a parent (e.g. second Word in a Line). In such a case, we measure from the previous Lower Right corner to the zone's lower left. X to the right and Y up.



See also file DjVuText.cpp and DjVuAnno.cpp in DjVuLibre.

Example (as passed to BZZ codec).

Consider the the following simple DjVu Image with 4 paragraphs of text as shown below.



At a binary level, the chunk looks like this:

0x0012F078 00 00 a1 74 65 78 74 65 ..¡texte 0x0012F080 78 61 6d 70 6c 65 2e 74 xample.t 0x0012F088 78 74 20 0a 1f 1d 54 68 xt ...Th 0x0012F090 69 73 20 74 65 78 74 20 is text 0x0012F098 69 73 20 0a 69 6e 20 74 is .in t 0x0012F0A0 68 65 20 63 6f 6c 75 6d he colum 0x0012F0A8 6e 20 0a 6f 6e 20 74 68 n .on th 0x0012F0B0 65 20 6c 65 66 74 2e 20 e left. 0x0012F0B8 0a 1f 1d 54 68 69 73 20 ...This 0x0012F0C0 74 65 78 74 20 69 73 20 text is 0x0012F0C8 0a 6f 6e 20 74 68 65 20 .on the 0x0012F0D0 72 69 67 68 74 2e 20 0a right. . 0x0012F0D8 4d 6f 73 74 20 4f 43 52 Most OCR 0x0012F0E0 20 45 6e 67 69 6e 65 73 Engines 0x0012F0E8 20 0a 77 69 6c 6c 20 63 .will c 0x0012F0F0 6f 72 72 65 63 74 6c 79 orrectly 0x0012F0F8 20 0a 67 72 6f 75 70 20 .group 0x0012F100 69 74 20 74 6f 67 65 74 it toget 0x0012F108 68 65 72 2e 20 0a 1f 1d her. ... 0x0012F110 50 61 67 65 20 31 20 0a Page 1 . 0x0012F118 1f 1d 0b 00 01 01 81 21 .....▯ !	*lenText* = 0xA1 (161 bytes) *strText* (as shown). Note the presence of LF (0x0A), US (0x1F) and RS (0x1D) embedded within the text. These optional, non-printable characters are often used to partition text layout regions (e.g. columns, side-blocks, etc) Note also that the string starts at 0x12F07B (following *lenText*), extends 161 bytes and ends at 12F11B (terminating NULL)
T X Y W H O Len nChild 289 118 1441 3063 161¶ 0x0012E51D 01 81 21 80 76 85 a1 8b f7 80 00 00 00 a1 00 00 01¶	Page Zone

```
                0     0     1441  3063        160
0x0012E52E  02 80 00 80 00 85 a1 8b f7 80 00 00 00 a0 00 00 04¶
                801   0     366   40          19¶
0x0012E53F  03 83 21 80 00 81 6e 80 28 80 00 00 00 13 00 00 01
                0     0     366   40          18¶
0x0012E550  04 80 00 80 00 81 6e 80 28 80 00 00 00 12 00 00 01¶
                0     0     366   40          17¶
0x0012E561  05 80 00 80 00 81 6e 80 28 80 00 00 00 11 00 00 01¶
                0     0     366   40          16¶
0x0012E572  06 80 00 80 00 81 6e 80 28 80 00 00 00 10 00 00 00
                -1167 -197  322   114         45
0x0012E583  03 7b 71 7f 3b 81 42 80 72 80 00 00 00 2d 00 00 01
                0     0     322   114         44¶
0x0012E594  04 80 00 80 00 81 42 80 72 80 00 00 00 2c 00 00 03
                0     0     296   32          14¶
0x0012E5A5  05 80 00 80 00 81 28 80 20 80 00 00 00 0e 00 00 03¶
                0     0     96    32          5¶
0x0012E5B6  06 80 00 80 00 80 60 80 20 80 00 00 00 05 00 00 00¶
                31    0     95    26          5¶
0x0012E5C7  06 80 1f 80 00 80 5f 80 1a 80 00 00 00 05 00 00 00¶
                31    0     43    32          3¶
0x0012E5D8  06 80 1f 80 00 80 2b 80 20 80 00 00 00 03 00 00 00¶
                3     9     319   32          15¶
0x0012E5E9  05 80 03 80 09 81 3f 80 20 80 00 00 00 0f 00 00 03¶
0x0012E5FA  06 80 00 80 00 80 2c 80 20 80 00 00 00 03 00 00 00¶
0x0012E60B  06 80 1e 80 00 80 46 80 20 80 00 00 00 04 00 00 00¶
0x0012E61C  06 80 1e 80 00 80 91 80 20 80 00 00 00 07 00 00 00¶
0x0012E62D  05 7f fe 80 09 81 21 80 20 80 00 00 00 0e 00 00 03¶
0x0012E63E  06 80 00 80 0a 80 2e 80 16 80 00 00 00 03 00 00 00¶
0x0012E64F  06 80 1e 80 00 80 46 80 20 80 00 00 00 04 00 00 00¶
0x0012E660  06 80 1f 80 00 80 70 80 20 80 00 00 00 06 00 00 00¶
0x0012E671  03 82 a5 7f a6 81 ba 80 cc 80 00 00 00 55 00 00 01¶
0x0012E682  04 80 00 80 00 81 ba 80 cc 80 00 00 00 54 00 00 05¶
0x0012E693  05 80 01 80 00 81 28 80 20 80 00 00 00 0e 00 00 03¶
0x0012E6A4  06 80 00 80 00 80 60 80 20 80 00 00 00 05 00 00 00¶
0x0012E6B5  06 80 1f 80 00 80 5f 80 1a 80 00 00 00 05 00 00 00¶
0x0012E6C6  06 80 1f 80 00 80 2b 80 20 80 00 00 00 03 00 00 00¶
0x0012E6D7  05 80 01 80 09 81 3a 80 28 80 00 00 00 0f 00 00 03¶
0x0012E6E8  06 80 00 80 0a 80 2e 80 16 80 00 00 00 03 00 00 00¶
0x0012E6F9  06 80 1e 80 00 80 46 80 20 80 00 00 00 04 00 00 00¶
0x0012E70A  06 80 21 7f f8 80 87 80 28 80 00 00 00 07 00 00 00¶
0x0012E71B  05 80 00 80 01 81 8b 80 28 80 00 00 00 12 00 00 03¶
0x0012E72C  06 80 00 80 06 80 60 80 1a 80 00 00 00 05 00 00 00¶
0x0012E73D  06 80 1c 80 00 80 4a 80 1a 80 00 00 00 04 00 00 00¶
0x0012E74E  06 80 1d 7f f8 80 a8 80 28 80 00 00 00 08 00 00 00¶
0x0012E75F  05 7f fe 80 01 81 5e 80 28 80 00 00 00 10 00 00 02¶
0x0012E770  06 80 00 80 00 80 5c 80 20 80 00 00 00 05 00 00 00¶
0x0012E781  06 80 24 7f f8 80 de 80 28 80 00 00 00 0a 00 00 00¶
0x0012E792  05 80 03 80 01 81 b7 80 28 80 00 00 00 14 00 00 03¶
```

Column

Region 1 of 4

Paragraph 1

Line 1

Word 1

Region 2 of 4

Paragraph 1

Line 1

(A note to the very observant: the addresses here are different than those in the above. This is a documentation artifact and not reflective of missing bytes! All bytes in this example are contiguous.

0x0012E7A3 06 80 00 80 0a 80 79 80 1e 80 00 00 00 06 00 00 00¶ 0x0012E7B4 06 80 1e 80 08 80 2c 80 20 80 00 00 00 03 00 00 00¶ 0x0012E7C5 06 80 1e 7f f8 80 d6 80 28 80 00 00 00 0a 00 00 00¶ 0x0012E7D6 03 7d f1 75 50 80 90 80 26 80 00 00 00 0a 00 00 01¶ 0x0012E7E7 04 80 00 80 00 80 90 80 26 80 00 00 00 09 00 00 01¶ 0x0012E7F8 05 80 00 80 00 80 90 80 26 80 00 00 00 08 00 00 02¶ 0x0012E809 06 80 00 80 04 80 5d 80 22 80 00 00 00 05 00 00 00¶ 0x0012E81A 06 80 1f 80 08 80 14 80 1e 80 00 00 00 02 00 00 00¶	

8.3.6 Bitonal Mask Chunk: Sjbz

Bitonal data is used to encoded using the jb2 shape-matching compression technique. Details are provided in Appendix 2

8.3.7 Foreground Wavelet Chunk: FG44

A compound djvu image may contain a single FG44 chunk which contains the foreground color. The content of this chunk is described in detail in Appendix 1

8.3.8 Background Wavelet Chunk: BG44

A compound djvu image may contain a multiple BG44 chunks which contain the background color. The content of these chunks is described in detail in in Appendix 1.

8.3.9 Thumbnail Wavelet Chunk: TH44

Multipage document file optionally can contain thumbnails for some or all pages. These thumbnails are stored into special component files containing thumbnails for a number of consecutive pages.

The thumbnail component file is composed of a single "FORM:THUM" containing one or more TH44 chunks. Each TH44 chunk contains one IW44 encoded thumbnail image for one page. See *Appendix 1*.

8.3.10 Foreground Color JB2 Chunk: FGbz

A compound djvu image may contain a single FGbz chunk containing the foreground colors.

Byte	Version	High order bit indicates that there is shape table correspondence data (below) Lower seven bits are the version, currently 0.
Palette Data		
INT16	nPaletteSize	Number of palette entries: 0 > nPaletteSize < 65535
BYTE3	bgrColor	Palette entries. 3 bytes each. BGR order.
JB2 Correspondence Data (see version)		
INT24	nDataSize	Number of JB2 blits which will be colored
INT16	Index0,	BZZ encoded indices. Index0 is the color of JB2 blit 0, etc.

	index1, …	

See also file DjVuPalette.cpp in DjVuLibre.

8.3.11 Document Info Chunk: INFO

As discussed in *Single Page Documents*, every DjVu image requires an INFO chunk and this must be the first (non-container) chunk. The INFO chunk data consists of seven fields in 10 bytes:

INT16	Width	A two-byte unsigned integer, most significant byte first, specifying the width of the image in pixels.
INT16	Height	A two-byte unsigned integer, most significant byte first, specifying the height of the image in pixels.
BYTE	Minor Version	A one-byte unsigned integer, specifying the minor version number of the encoder being used. Currently 26
BYTE	Major Version	A one-byte unsigned integer, specifying the major version number of the encoder being used. Currently 0.
INT16	Dpi	A two-byte unsigned integer, least significant byte first, specifying the spatial resolution of the image in dots per inch (dots per 2.54 cm).
BYTE	Gamma	A one-byte unsigned integer, equal to 10 times the gamma of the device on which the image is expected to be rendered
BYTE	Flags	Mask to be interpretted as follows: The first 5 bits are reserved for future implementations The last 3 bits specify the image's rotation. The following 4 patterns are recognized: 1 – 0° (rightside up) 6 – 90° Counter Clockwise 2 – 180° (unside down) 5 – 90° Clockwise Note that the rotation affects the any coordinates in the Annotation chunk.

Any additional data in the INFO chunk is to be ignored.

Example:

0000010: 494e 464f IFF Chunk ID="INFO";

0000014: 0000 000a IFF Size=10 bytes

0000018: 089a 03c7 width=2202; height=967

000001c: 1a00 2c01 version=26; resolution=300dpi (LSB)

0000020: 1601 536a gamma*10=22; flags=0x01;

See also file DjVuInfo.cpp in DjVuLibre.

A note about the version field.

The intent of the version field is to allow decoders to recognized files based on later versions of the file format (and which they may, therefore, not be completely prepared to interpret). An approximate history of changes follows:

Minor Version	Date	Notes
20	1999 April	DjVu version 3. "old indirect format" (initial Multipage support), DjVuAnno chunk
21	1999 September	"new indirect format" DjVuText chunk
22	2001 April	Orientation Color JB2
23	2002 July	CID chunk (obsolete)
24	2003 February	LTAnno chunk (obsolete)
25	2003 May	NAVM chunk
26	2005 April	Text / Line annotations

8.3.12 INCL

This is the counterpart to the FORM:DjVi chunk which provides document-level ("shared") information. The INCL chunk simply contains the (unencoded) UTF8 encoded ID of the included component file. To obtain the data for this chunk, the decoder should look for this ID at in the governing DIRM chunk. The corresponding chunk must be of type FORM:DJVI and contain the shared chunk.

8.3.13 Background JPEG Chunk: BGjp

The background in DjVu file is typically stored in one or more BG44 chunks. As an alternative, the background can be stored using the traditional JPEG encoding. Simply write the JPEG bytestream to the contents of the chunk. See Reference 3 for details of this stream.

8.3.14 Foreground JPEG Chunk: BFjp

The foreground in DjVu file is typically stored in one or more BG44 chunks. As an alternative, the foreground can be stored using the traditional JPEG encoding. Simply write the JPEG bytestream to the contents of the chunk. See Reference 3 for details of this stream.

8.3.15 Foreground MMR Chunk: Smmr

The mask in a DjVu file is typically stored in the Sjbz chunk. As an alternative, the mask may be encoded using the traditional MMR encoding.

The Smmr chunk type can be used as an alternative to the Sjbz chunk to encode the mask data. The Smmr chunk data consists of:

BYTE*3	Magic	'M' 'M' 'R'

BYTE	Flags	0xb000000<s><i>. <i> is similar to TIFF's 'min-is-black' tag. It is set for a reverse video image. <s> is set to indictate that the MMR data is in stripes
INT16	Width	Width of image. (MSB first)
INT16	Height	Height of image. (MSB first)

Following this header is either the "regular" MMR encoded data or (if flags.s is set) the striped data format consisting

INT16	Rps	Rows per stripe
INT32	Nbytes0	Number of bytes in the first stripe
BYTE*	Mmrdata0	The MMR encoded data for the first stripe
INT32	Nbytes1	Number of bytes in the second stripe
BYTE*	Mmrdata1	The MMR encoded data for the second stripe
…		

See also (a) Reference 5 "G4" and (b) file MMRDecoder.cpp in DjVuLibre.

9 DjVu in the Raw (binary and IFF level dumps)

9.1 Single Page Example (FORM:DjVu)

0000000: 4154 2654 464f 524d 0000 68a6 444a 5655 AT&TFORM..h¦DJVU 0000010: 494e 464f 0000 000a 089a 03c7 1a00 2c01 INFO.....Ç...,. 0000020: 1601 536a 627a 0000 334d 800f 64de 94a4 ..Sjbz..3M..dÞ.. 0000030: 2734 d181 668a 6864 6061 d987 ea98 4af3 '4Ñ.f.hd`aÙ.ê.Jó 0000040: 41d7 a905 9054 ca3d 0ed0 5a9f a004 2fa1 A....TÊ=.ÐZ.../. 0000050: f3dd d4ef 202b fc9f 49a6 e23d e4b6 c1ed óÝÔï +ü.I¦â=ä.Áí 0000060: 6fae ac0e f9e0 8dd4 fe94 18c8 0fa1 2ae2 o...ùà.Ôþ..È..*â 0000070: fb94 82fe 3b2b 098a d772 8638 349f 0118 û..þ;+...r.84... 0000080: e59c 3ded f685 c8a6 9df5 944f 80cd 9d0d å.=íö.È¦.õ.O.Í..	FORM:DJVU [26790] ; note IFF length field (0x68A6) INFO [10] DjVu 2202x967, v26, 300 dpi, gamma=2.2 Sjbz [13133] JB2 bilevel data (BZZ Encoded)
0003320: dde6 b770 ac01 1495 cec1 2b48 44c4 2f99 Ýæ.p....ÎÁ+HDÄ/. 0003330: ce7f ffff 6046 5fcf 555a 471f 71bd e270 Î.ÿÿ`F_ÏUZG.q½âp 0003340: b37a 7899 68ba e344 0412 128b f65f ffff .zx.hºãD....ö_ÿÿ 0003350: 9db5 a6a1 70cf 58cc 0378 183b d0cf c8e0 .µ¦.pÏXÌ.x.;ÐÏÈà 0003360: 17ab 221b 9cd6 f1e1 d1fa b820 e0ab 8099 ..".. ÖñáÑú¸à... 0003370: b4c3 f320 7361 8700 4647 3434 0000 00b9 ´Ãó sa..FG44.... 0003380: 004c 0102 00b8 0051 80ff f0cd b97f 5015 .L...¸.Q.ÿðÍ..P. 0003390: e227 b61f 6dad 3543 71d3 3fff ffff ff6d â'..m.5CqÓ?ÿÿÿÿm 00033a0: 0936 38d2 0e2a f4af 6a25 21c2 ffff f661 .68Ò.*ô.j%!Âÿÿöa 00033b0: 375b 82ac 610c c600 4aac 9843 a4f9 cb93 7[..a.Æ.J..C.ùË. 00033c0: 0edb 777e 53b8 0916 7887 6434 2a7d db32 .Ûw~S¸..x.d4*}Û2 00033d0: 132b 204f b60e ff27 9dc2 ba3c c1cf 9fe8 .+ O..ÿ'.Âº<ÁÏ.è 00033e0: 4d2f 598c 2aef 2d75 51d2 620f 894c 92a7 M/Y.*ï-uQÒb..L.. 00033f0: 9cdd 1f0a 64ab dc50 890e f6a2 06aa 1ae9 .Ý..d.ÜP..ö..ª.é 0003400: a0e8 18db fb89 aad5 9e1a 5046 a546 a0fc .è.Ûû.ªÕ..PF.F.ü 0003410: 955a dd1c fbcc 9bc5 bcb0 fa55 1052 a20f .ZÝ.ûÌ.Å¼.úU.R..	FG44 [185] IW44 data #1, 76 slices, v1.2 (color), 184x81

0003400: a0e8 18db fb89 aad5 9e1a 5046 a546 a0fc . è. Ûû. ªÕ. . PF. F. ü 0003410: 955a dd1c fbcc 9bc5 bcb0 fa55 1052 a20f . ZÝ. ûÌ. Å¼. úU. R. . 0003420: ec35 707c 750e fed7 be89 fb70 101c 293a ì5p|u. þ. ¾. ûp. .) : 0003430: d6e8 6185 c2ed cabc 1700 4247 3434 0000 Öèa. ÂíÊ¼. . BG44. . 0003440: 03a7 004a 0102 02de 0143 8afa 048f 09d4 . . . J. . . Þ. C. ú. . . Ô 0003450: 3488 2e32 9043 cf43 d341 caeb 85c6 1553 4. . 2. CÏCÓAÊë. Æ. S 0003460: 412d 8382 81a4 454e 7fff ffff ffff aeb8 A-. . . . EN. ÿÿÿÿÿ. ¸ 0003470: afff ffff ffff ffff ffff ffff ffff ffff . ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ 0003480: ffff ffff b03b 7ffc 63ca 673e 4bfb 52dc ÿÿÿÿ. ;. ücÊg>KûRÜ 0003490: d2a6 5ae6 7e9f f6ee 3da4 cb7e 826e 9c00 Ò¦Zæ~. öî=. Ë~. n. . 00034a0: 0023 92e4 8a7c 1480 777c 7d11 2f48 8bb1 . #. ä. |. . w|}. /H. . 00034b0: f43d 652f 3b4f 08a0 f36e dfe9 3f0f 6f0c ô=e/;O. . ónßé?. o. 00034c0: c928 36ae 4a38 a87c 4920 2ec0 6d9e 4dff É(6. J8¨|I . À m. Mÿ 00034d0: 705a 7a48 b72e 6000 0003 7685 277f ffff pZzH. . `. . . v. '. ÿÿ 00034e0: fffc 4f28 1d0b 4b61 4e25 54f3 ecaf fa7c ÿüO(. . KaN%Tói. ú|	BG44 [935] IW44data #1, 74 slices, v1.2 (color), 734x323
00037d0: 5bba 3cc5 490a 2044 d8fd 5183 06ac 9a43 [º<ÅI. DØýQ. . . . C 00037e0: 6df1 046c a110 26e7 0400 4247 3434 0000 mñ. l. . &ç. . BG44. . 00037f0: 0688 010a 0538 46fc 1abf 10aa e1a1 f94e . . . . . 8Fü. . . ªá. ùN 0003800: 1b27 bab5 eead debc 7685 17a8 9b72 1439 . ' ºµî. Þ¼v. . ¨. r. 9 0003810: 5ab8 028a bae0 b76b 93e6 3da8 9d1b c20d Z¸. . ºà. k. æ=¨. . Â. 0003820: 66f1 bfe5 f839 007e d95a 728f 9213 8089 fñ. åø9. ~ÙZr. . . . . 0003830: 56e0 f911 7e57 b47f 188b 0b5f b7ac 41bc Vàù. ~W´. . . . _. . A¼ 0003840: 1d78 d819 d806 4db4 0fb7 3eed e653 fdb1 . xØ. Ø. M´. . >íæSý. 0003850: 163d 0674 6119 f84f 572c 06c9 e66a cafe . =. ta. øOW, . Éæj Êþ	BG44 [1672] IW44 data #2, 10 slices …

9.2 A multipage example (FORM:DjVm)

```
FORM:DJVM [126475]
  DIRM [59]          Document directory (bundled, 3 files 2 pages)
  FORM:DJVI [3493] {dict0002.iff}
```

<table>
<tr><td colspan="2">FORM:DJVU [115016] {p0001.djvu}
FORM:DJVU [7869] {p0002.djvu}</td></tr>
<tr><td>-bash-3.00$ xxd -s 0 -l 32 mpage.djvu
0000000: 4154 2654 464f 524d 0001 ee0b 444a 564d AT&TFORM....DJVM
0000010: 4449 524d 0000 003b 8100 0300 0000 5400 DIRM...;.....T.

-bash-3.00$ xxd -s 84 -l 32 mpage.djvu
0000054: 464f 524d 0000 0da5 444a 5649 446a 627a FORM....DJVIDjbz
0000064: 0000 0d99 e6fd f53e ad32 cbe9 0704 2c58 ....>.2....,X

-bash-3.00$ xxd -s 3586 -l 32 mpage.djvu
0000e02: 464f 524d 0001 c148 444a 5655 494e 464f FORM...HDJVUINFO
0000e12: 0000 000a 09eb 0cdf 1900 2c01 1601 4349 CI

-bash-3.00$ xxd -s 118610 -l 32 mpage.djvu
001cf52: 464f 524d 0000 1ebd 444a 5655 494e 464f FORM....DJVUINFO
001cf62: 0000 000a 09eb 0cdf 1900 2c01 1601 4349 ....CI</td><td>FORM:DJVM [126475]
DIRM [59]

Not shown: 0x10+8(header)+59(length)
FORM:DJVI [3493]
Not shown: 0x64+8(header)+0xda5(length)
FORM:DJVU [115016]

etc</td></tr>
</table>

10 Appendix 1: IW44 coding.

This section describes the coding of chunks of type BG44, FG44, PM44, BM44, and TH44. Chunks of type BG44, FG44, and TH44 may be color or grayscale chunks. Chunks of type PM44 are color chunks. Chunks of type BM44 are grayscale chunks. All of these color and grayscale chunk types have the same structure. The chunk consists of a chunk header followed by arithmetically coded wavelet coefficient updates. The coefficients are organized in a hierarchical fashion.

10.1 Definitions

Color component. Compound DJVU Images and Photo DJVU Images contain color or grayscale image data. Color IW44 Images contain color image data. Grayscale IW44 Images contain grayscale image data. Color image data is coded using three color components, called Y, Cb, and Cr. These correspond to the usual YCbCr color space, adjusted to facilitate transformation to the RGB color space. Grayscale image data is coded using one color component, called Y. This corresponds to the grayscale intensity of the image.

Color layer. A color layer is any of:

- The foreground layer of a Compound DJVU Image, coded in one FG44 chunk
- The background layer of a Compound DJVU Image, coded in one or more BG44 chunks
- The only layer of a Photo DJVU Image, coded in one or more BG44 chunks
- The only layer of a Color IW44 Image, coded in one or more PM44 chunks
- The only layer of a Grayscale IW44 Image, coded in one or more BM44 chunks

Color chunk. A color chunk is a chunk of type BG44, FG44, PM44, or BM44. A color chunk contains wavelet coefficient update information for one or three color components.

Block. A rectangular array of pixels of size 32 x 32 or less. The blocks are numbered starting in the lower left corner of the image. All blocks are 32 x 32 except possibly those along the right edge or top edge; those blocks may be smaller if the image dimensions are not divisible by 32.

Block count. The number of blocks in the image, denoted by NB.

Wavelet block. The set of coefficients associated with one block of the image, in one color component. There are 1024 wavelet coefficients in a wavelet block, numbered 0 through 1023. The coefficients in a wavelet block have effects on the reconstruction of other blocks in the image, but for coding purposes they are considered to be localized within the block in which they are coded.

Bucket. A particular set of 16 wavelet coefficients within a wavelet block. A wavelet block consists of 64 buckets, numbered 0 through 63. Table 2 gives the correspondence between coefficients and buckets.

Band number	Coefficient indices	Bucket indices

0	0-15	0
1	16-31	1
2	32-47	2
3	48-63	3
4	64-127	4-7
5	128-191	8-11
6	192-255	12-15
7	256-511	16-31
8	512-767	32-47
9	768-1023	48-63

Table 2: Wavelete coefficient bands

Band. A subset of wavelet coefficients for a given color component. There are 10 bands. The correspondence among band numbers, coefficient coefficients, and bucket coefficients is given by Table 2.

Cycle. Data for one color component consisting of coefficient updates for all coefficients, that is, for all 10 bands, starting with band 0. Within one band, only some coefficients are updated, but within a cycle, all coefficients are updated. The last cycle of a color component may have fewer than 10 bands.

Color band number. The current band number for a color component. Each color component's color band number starts at 0, and increases by 1 at the end of selected slices until it reaches 9; then it is reset to 0.

Color band. A collection of update information for a subset of the coefficients of one color component of the image, consisting of updates of all the coefficients in the image whose indices within their respective blocks are those corresponding to the current color band's color band number.

Slice. A slice is the highest level subdivision of a color chunk. A slice contains data for one color band for each of the color components in a color layer, that is, for three color components for a color image, or for one color component for a grayscale image.

Block band. A collection of update information for a subset of the coefficients of one color component of a wavelet block, consisting of updates of the coefficients in the block whose indices are those corresponding to a given band.

Chrominance delay counter. An integer counter that indicates how many slices in a color layer contain a color band only for the Y color component, and not for the Cb and Cr color components. The chrominance delay counter is initially set to the value specified in the INFO chunk for the color layer, and decremented by i after each slice in the color layer until it reaches 0. See the section on Band counting below.

Step size table. A table that indicates the precision to which each coefficient in a color component is currently stored. There are three such tables for a given color layer, one for

each color component. Each such table has 16 entries. Each entry specifies the current step size for 1, 4, 16, 64, or 256 different coefficient indices, according to Table 3.

10.2 Color chunks within an DjVu file

There may be more than one BG44 or PM44 or BM44 chunks in a DjVu file. If there is more than one such color chunk, the coefficient updating is continuous across the chunks, and the data is taken from the chunks in the order in which they appear in the file. Nothing is reinitialized at the beginning of chunks after the first color chunk of these types, except for the low level arithmetic coder. The probability estimates for the arithmetic coder are not reinitialized.

In a Compound DJVU Image file, in which both an FG44 chunk and one or more BG44 chunks appear in the same file, the coding of the foreground layer, using the FG44 chunk, is independent of the coding of the background layer, using the BG44 chunks.

Each color layer is coded using a Dubuc- Deslauriers - Lemire (4, 4) Interpolative Wavelet Transform. Each layer of the image is transformed into a set of wavelet coefficients, one wavelet coefficient for each pixel in the original image. This transform is especially effective for coding images at high compression ratios.

The value of each coefficient is coded in a distributed fashion, through a number of cycles. Within one cycle, each coefficient is updated once (that is, in only one of the l0 bands), and receives approximately one additional bit of information. Specifically, from cycle to cycle the absolute value of a coefficient is first narrowed down by eliminating possible values for the most significant non-zero bit until the correct most significant non-zero bit is found. The sign is coded in the same cycle in which the most significant non-zero bit is found. Then in each subsequent cycle, one additional bit of the value is coded.

10.3 Color chunk data headers

A color chunk begin with a data header consisting of 2 or 9 octets, as follows:

Serial number. A one-octet unsigned integer. The serial number of the first chunk of a given chunk type is 0. Successive chunks are assigned consecutive serial numbers.

Number of slices. A one-octet unsigned integer. The number of slices coded in the chunk.

Major version number and color type. One octet containing two values, present only if the serial number is 0. The least significant seven bits designate the major version number of the standard being implemented by the decoder. For this version of the standard, the major version number is 1. The most significant bit is the color type bit. The color type bit is 0 if the chunk describes three color components. The color type bit is I if the chunk describes one color component.

Minor version number. A one-octet unsigned integer, present only if the serial umber is 0. This octet designates the minor version number of the standard being implemented by the decoder. For this version of the standard, the minor version number is 2.

Image width. A two-octet unsigned integer, most significant octet first, present only if the serial number is 0. This field indicates the number of pixels in each row of the image

described by the current chunk. The image width will be less than the width of the original image if the chunk describes a layer coded at lower resolution than the original image. For a BG44 or FG44 chunk, if W is the width of the original image specified in the INFO chunk, and w is the width of the image described by the current chunk, then the allowable values of w are:

$$\left\lceil \frac{W}{1} \right\rceil, \left\lceil \frac{W}{2} \right\rceil, \left\lceil \frac{W}{3} \right\rceil, \left\lceil \frac{W}{4} \right\rceil, \left\lceil \frac{W}{5} \right\rceil, \left\lceil \frac{W}{6} \right\rceil, \left\lceil \frac{W}{7} \right\rceil, \left\lceil \frac{W}{8} \right\rceil, \left\lceil \frac{W}{9} \right\rceil, \left\lceil \frac{W}{10} \right\rceil, \left\lceil \frac{W}{11} \right\rceil, \text{and } \left\lceil \frac{W}{12} \right\rceil$$

For a BM44 or PM44 chunk, there are no restrictions on the image width.

Image height. A two-octet unsigned integer, most significant octet first, present only if the serial number is 0. This field indicates the number of pixels in each column of the image described by the current chunk. The image height will be less than the height of the original image if the chunk describes a layer coded at lower resolution than the original image. For a BG44 or FG44 chunk, if H is the height of the original image specified in the INFO chunk, and h is the height of the image described by the current chunk, then the allowable values of h are:

$$\left\lceil \frac{H}{1} \right\rceil, \left\lceil \frac{H}{2} \right\rceil, \left\lceil \frac{H}{3} \right\rceil, \left\lceil \frac{H}{4} \right\rceil, \left\lceil \frac{H}{5} \right\rceil, \left\lceil \frac{H}{6} \right\rceil, \left\lceil \frac{H}{7} \right\rceil, \left\lceil \frac{H}{8} \right\rceil, \left\lceil \frac{H}{9} \right\rceil, \left\lceil \frac{H}{10} \right\rceil, \left\lceil \frac{H}{11} \right\rceil, \text{and } \left\lceil \frac{H}{12} \right\rceil$$

For a BG44 or FG44 chunk, It must be the case that

$$\left\lceil \frac{W}{w} \right\rceil = \left\lceil \frac{H}{h} \right\rceil$$

For a BM44 or PM44 chunk, there are no restrictions on the image width.

Initial value of chrominance delay counter. A one-octet unsigned integer, present only if the serial number is 0. Only the least significant seven bits are used. The most significant bit is ignored, but should be set to I by an encoder. This field specifies the initial value of the chrominance delay counter, used as described below.

10.4 Color chunk data

10.4.1 Hierarchical structure of a coded color layer

The data coded in a color chunk consists of information needed to reconstruct wavelet coefficients. There are one or three color components; each color component has its own set of wavelet coefficients. Within a color component, there are 1024 wavelet coefficients for each 32 x 32 block of the image.

Within one layer (background or foreground for a DJVU Image, or the only layer for an IW44 Image), coding is divided into a series of slices. All the slices may be coded in one chunk, or they may be separated into a number of chunks. The only difference it makes whether the slices are coded in one chunk or in several chunks is in the order of progressive rendering; the final reconstructed image will be the same. The number of slices in each chunk is specified in the color chunk data header. One slice contains refinement data for one color band for each color component. Within a color component, all coefficients in a slice are in the same band.

A color chunk describes the full image at the spatial resolution implied by the image width and image height fields in the data header of the first chunk of the same type as the current color chunk.

The sequence of color components within a slice is: first Y, then Cb, then Cr, although the Cb and Cr components are not present in a slice if the chunk describes grayscale data or if the chrominance delay counter is not equal to 0 at the time the slice is coded.

A color band is made up of coefficient updates for all blocks in the image, but only for coefficients that are in the currently active band for the color component. Each block's set of updates within a color band is called a block band. The block bands are coded block by block, first from left to right within the bottom row, then by rows moving up the image, left to right within each row.

Within a block band, there are 16, 64, or 256 coefficient updates. The coefficients being updated are divided into buckets, each bucket containing 16 coefficients. Thus, a block band contains 1, 4, or 16 buckets. The buckets and coefficients being updated are determined by the color band number according to Table 2.

10.4.1.1 Band counting.

The header of the first color chunk contains an initial value for the chrominance delay counter. It may be 0 or a positive integer.

At the beginning of the first color chunk, the color band number for each of the three color components is set to 0.

At the beginning of each slice, the chrominance delay counter is tested. If the chrominance delay counter is 0 and if the slice describes color image data, then all three color components are present. If the chrominance delay counter is greater than 0 or if the chunk describes grayscale image data, only the Y color component is present for the slice.

At the end of a slice, the following actions take place:

- The color band number is increased by 1 for the Y component. If the new color band number exceeds 9, it is set to 0.
- If the chrominance delay counter is 0, the color band numbers for the Cb and C r components are increased by 1. If the new color band numbers exceed 9, they are set to 0. (Note: The color band numbers for the Cb and Cr components are always equal to each other.)
- If the chrominance delay counter is greater than 0, it is decreased by 1.

A color chunk ends when the number of slices specified in the color chunk header have been coded. At the beginning of each color chunk after the first for a given color layer, the chrominance delay counter and color band numbers retain the values they had at the end of the previous color chunk.

10.4.2 Quantization of coefficients

At each point during the decoding process, each wavelet coefficient has been determined to a certain precision. The current value a of the coefficient is stored, and a current step

size S is associated with the coefficient. The current step size for each coefficient is governed by a step size table. The index of the entry in the step size table that contains the step size for a given coefficient is given in Table 3.

If $a \neq 0$, the coefficient is said to be "active". If $a > 0$, the range of possible actual values of the coefficient is $[a - S, a + S)$. If $a < 0$, the range of possible actual values of the coefficient is $(a - S, a + S]$. If $a = 0$, the coefficient is not active, and the range of possible actual values of the coefficient is $(-2S, 2S)$.

When the value of a given coefficient is updated, there are three cases.

1. If the coefficient is not active ($a = 0$), then there are three possibilities for the next current interval: $(-2S,-S]$, $(-S,S)$, or $[S, 2S)$. If the coefficient remains not active, then the next interval is $(-S, S)$. Otherwise, the sign of the coefficient is decoded to choose between the other two intervals.
2. If the coefficient is active and $a > 0$, then there are two possibilities for the next current interval: $[a - S, a)$ or $[a, a + S)$. The next decision for the coefficient is the increase coefficient absolute value decision. If this decision is YES, then $[a, a + S)$ is the next interval. If the decision is NO, then $[a - S, a)$ is the next interval.
3. If the coefficient is active and $a < 0$, then there are two possibilities for the next current interval: $(a - S, a]$ or $(a, a + S]$. The next decision for the coefficient is the increase coefficient absolute value decision. If this decision is YES, then $(a - S, a]$ is the next interval. If the decision is NO, then $(a, a + S]$ is the next interval.

Coefficient index	**Index into step size table**
0	0
1	1
2	2
3	3
4-7	4
8-11	5
12-15	6
16-31	7
32-47	8
48-63	9
64-127	10
128-191	11
192-255	12
256-511	13
512-767	14

768-1023	15

Table 3: Step size table indices related to wavelet coefficient indices

10.4.2.1 Initialization of step sizes

The initial values of the step sizes are given in Table 4. There is a separate table of step sizes for each color component. Each color component's table is given the same initial values.

10.4.2.2 Reduction of step sizes.

Each slice contains one band of coefficient update information for each color component. At the end of a slice, the step sizes are divided by 2 for the current band for each color component. The indices of the step sizes to be reduced for each band are given in Table 5. For a given color band, either i or 7 step sizes are reduced.

Non-zero step sizes are always integer powers of 2. When a step size of i is divided by 2, the result is set to 0.

10.5 Coefficient updating

Within a block band, each coefficient in the block band may be updated. A block band is decoded by a preliminary flag computation followed by four passes. One or more of the passes may be skipped or may not require any decoding, depending on conditions present at the beginning of the block band's coding and on tests made during the decoding of previous passes with the block band. The 4 passes are:

1. Decoding the decode buckets decision for the block band.
2. Decoding the decode coefficients decision for buckets in the block band.
3. Decoding the activate coefficient decision for coefficients in the block band, and determining the sign of newly activated coefficients.
4. Decoding the update decisions for previously active coefficients.

Step size Initial	Table index value
0	0x04000
1	0x08000
2	0x08000
3	0x10000
4	0x10000
5	0x10000
6	0x20000
7	0x20000

8	0x20000
9	0x40000
10	0x40000
11	0x40000
12	0x80000
13	0x40000
14	0x40000
15	0x80000

Table 4: Initialization of step sizes

During the coefficient updating process, a number of binary decisions are decoded. Each decision is decoded using the Z´-Coder. Decoding a decision using the Z´-Coder may be done with a conditioning context, or it may be done using the pass-through mode of the Z´-Coder. For color chunk decoding, there are up to 584 conditioning contexts, that is, up to 294 conditioning contexts for the background layer and up to 294 conditioning contexts for the foreground layer. Within a layer, there are 98 conditioning contexts for each color component; one or three color components may be present for each layer. The contexts are as follows:

- 1 context in each color component is for the decode buckets decision.
- 80 contexts in each color component are for the decode coefficients decision, 8 for each of the 10 bands.
- 16 contexts in each color component are for the activate coefficient decision.
- 1 context in each color component is for the increase coefficient absolute value decision.

Band number	Step size table indices
0	0-6
1	7
2	8
3	9
4	10
5	ll
6	12
7	13
8	14
9	15

Table 5: Step size reduction schedule

The coefficient sign is decoded using the pass-through mode of the Z´-Coder without a context. For all occurrences of the increase coefficient absolute value decision for any coefficient after the first such decision, the increase coefficient absolute value decision is coded using the pass-through mode of the Z´-Coder.

10.5.1 Preliminary flag computation.

Flags are computed for each coefficient in the block band, for each bucket in the block band, and for the block band as a whole.

1. Flag computation for coefficients. For each coefficient in a block band, there is a value of the step size. For each coefficient, there are two flag values, based on the value of the coefficient and the value of the coefficient's step size. The flags are called ACTIVE and POTENTIAL. At most one of the flag values may be SET for a coefficient in a given cycle. If the coefficient's step size is either 0 or greater than or equal to 0x8000, then both flag values are CLEAR. The two flag values are:
    a) ACTIVE: The coefficient's ACTIVE flag value is SET if the coefficient's step size is greater than 0 and less than 0x8000, and the coefficient's value is not 0. Otherwise the coefficient's ACTIVE flag value is CLEAR. The sign of the coefficient is known, and the position of the most significant non-zero bit of its absolute value is known.
    b) POTENTIAL: The coefficient's POTENTIAL flag value is SET if the coefficient's step size is greater than 0 and less than 0x8000, and the coefficient's value is 0. Otherwise the coefficient's POTENTIAL flag value is CLEAR. It is possible that the value of this coefficient will become non-zero during this cycle.
2. Flag computation for buckets. Each bucket has two flag values associated with it depending on the flags of the 16 coefficients in the bucket. The bucket flags have the same names as the coefficient flags. Both, one, or neither of the bucket flags may be SET for a bucket in a given cycle.
    a) ACTIVE: The bucket's ACTIVE flag is SET if any of the coefficients in the bucket have ACTIVE flags SET . Otherwise the bucket's ACTIVE flag value is CLEAR.
    b) POTENTIAL: The bucket's POTENTIAL flag is SET if any of the coefficients in the bucket have POTENTIAL flags SET. Otherwise the bucket's POTENTIAL flag value is CLEAR.
3. Flag computation for the block band. The block band has two flag values associated with it depending on the flags of the buckets in the block band. The block band flags have the same names as the bucket flags. Both, one, or neither of the block band flags may be SET for a block band in a given cycle. The block band flag values are not needed if the number of buckets in the block band is less than 16.

a) ACTIVE: The block band's ACTIVE flag is SET if any of the buckets in the block band have ACTIVE flags SET. Otherwise the block band's ACTIVE flag value is CLEAR .

b) POTENTIAL: The block band's POTENTIAL flag is SET if any of the buckets in the block band have POTENTIAL flags SET. Otherwise the block band's POTENTIAL flag value is CLEAR .

10.5.2 Block-band-decoding pass.

If the block band contains fewer than 16 buckets, the block-band-decoding pass is skipped and the bucket decoding pass is performed. If the block band's ACTIVE flag is SET, the block-band-decoding pass is skipped and the bucket decoding pass is performed. If the block band contains 16 buckets, and if the block band's ACTIVE flag is CLEAR, and if the block band's POTENTIAL flag is SET, then the decode buckets decision is decoded. If the decode buckets decision is YES, the bucket-decoding pass is performed for the block band. If the decode buckets decision is NO, the bucket-decoding pass and the newly-active-coefficient-decoding pass are skipped for the block band.

10.5.2.1 Arithmetic decoding.

For each color component, there is a single context for use in decoding the *decode buckets* decision. If the value returned by the Z´-Coder for the *decode buckets* decision is 1, then the value of the decode buckets decision is YES . If the value returned by the Z´-Coder is 0, then the value of the decode buckets decision is NO.

The Z´-Coder context for the decode buckets decision for each color component is initially set to 0.

10.5.3 Bucket-decoding pass.

Each bucket has a flag called the coefficient-decoding flag. If the bucket-decoding pass is not skipped, then for each bucket in the block band, if the bucket's POTENTIAL flag is SET, then the decode coefficients decision for the bucket is decoded. If the the decode coefficients decision is YES, then the bucket's coefficient-decoding flag is SET; otherwise it is CLEAR.

10.5.3.1 Arithmetic decoding.

For each color component, there are 80 contexts for use in decoding the *decode coefficients* decision. For each of the l0 bands in a color component, there are 8 contexts. There are four contexts that may be used if the block band's ACTIVE

flag is SET, and four contexts that may be used if the block band's ACTIVE flag is CLEAR. The index of the context to be used among the 4 possible contexts is computed as follows.

If the band number is 0, then no -- 0. Otherwise, the value of no is computed as follows:

1. The bucket number is multiplied by 4, giving a result t.

2. The coefficients numbered t, t+1, t+2, t+3 are examined, and the number n_0 of coefficients with value 0 among the four coefficients is counted.
3. If $n_0 = 4$, n_0 is reduced to 3.

Then the value of n_0 is used as the index to one of the four contexts, for the given color component, band, and block band ACTIVE flag value. If the value returned by the Z′-Coder for the decode coefficients decision is 1, then the value of the *decode coefficients* decision is YES . If the value returned by the Z′-Coder is 0, then the value of the *decode coefficients* decision is NO

Each of the 80 Z′-Coder contexts for the decode coefficients decision for each color component is initially set to 0.

10.5.4 Newly-active-coefficient-decoding pass.

If the newly-active-coefficient-decoding pass is not skipped, then for each bucket in the block band, the coefficient-decoding flag is tested. For a given bucket, if the bucket's coefficient- decoding flag is SET, then the following procedure is followed for each coefficient in the bucket: If the coefficient's POTENTIAL flag is SET, then the *activate coefficient* decision is decoded. If the the *activate coefficient* decision is YES, then the sign of the coefficient $s_{\pm}$ with value +1 or -1, is decoded. Then the coefficient is set equal to

$$\frac{3}{2} \times s_{\pm} \times \text{coefficient's step size.}$$

10.5.4.1 Arithmetic decoding.

For each color component, there are 16 contexts for use in decoding the *activate coefficient* decision. There are eight contexts that may be used if the block's ACTIVE flag is SET and eight contexts that may be used if the block's ACTIVE flag is

CLEAR.The index of the context to be used from among the 8 possible contexts is computed as follows:

1. The coefficients in the bucket are examined, and the number n_p of them whose POTENTIAL flag is SET is computed.
2. Loop through the coefficients whose POTENTIAL flag is SET.
    a. Compute $i_p = \min(7, n_p)$.
    b. Use i_p as the index into the set of 8 possible contexts, given the color component and value of the block's ACTIVE flag.
    c. Decode the *activate coefficient* decision using the context; if the *activate coefficient* decision is YES, decode the sign using the pass-through mode of the Z′-Coder, and set $n_p = 0$.
    d. If np> 0, decrement n_p by 1.

If the value returned by the Z′-Coder for the *activate coefficient* decision is 1, then the value of the activate coefficient decision is YES. If the value returned by the Z′-Coder is

0, then the value of the *activate coefficient* decision is NO. The decoding of the sign $s_{\pm}$ of a newly activated coefficient uses the pass-through mode of the Z′-Coder. If the value returned by the Z′-Coder is 1, then $s_{\pm} = -1$. If the value returned by the Z′-Coder is 0, then $s_{\pm} = +1$.

Each of the 16 Z′-Coder contexts for the *activate coefficients* decision for each color component is initially set to 0.

10.5.5 Previously-active-coefficient-decoding pass.

For all coefficients in the block band, the following procedure is followed: If the coefficient's ACTIVE flag is SET , the *increase coefficient absolute value* decision is decoded. If the decision is NO, the absolute value of the coefficient is reduced by half of the coefficient's step size. If the decision is YES, the absolute value of the coefficient is increased by half of the coefficient's step size. A step size of i is a special case. If the step size is i and the decision is NO, the absolute value of the coefficient is reduced by 1. If the step size is 1 and the decision is YES, the value of the coefficient is unchanged.

10.5.5.1 Arithmetic decoding.

For each color component, there is a single context for use in decoding the *increase coefficient absolute* value decision. This context is used to decode the *increase coefficient absolute* value decision if the absolute value of the coefficient is less than or equal to 3 times the value of the step size for the coefficient. Otherwise, the pass-through mode of the Z′-Coder is used. (Note: the effect of this test is that only the second most significant bit of a coefficient's value is decoded using this context; other less significant bits are decoded using the pass-through mode of the Z′-Coder, with no context.)

Whether the context or the pass-through mode is used, if the value returned by the Z′-Coder for the *increase coefficient absolute* value decision is 1, then the value of the *increase coefficient absolute value* decision is YES. If the value returned by the Z′-Coder is 0, then the value of the increase coefficient absolute value decision is NO.

The Z′-Coder context for the increase coefficient absolute value decision for each color component is initially set to 0.

10.6 Image reconstruction

At any time during the decoding process, an image may be reconstructed from the current values of the wavelet coefficients already decoded. The wavelet coefficients are stored in three two-dimensional arrays one for each of the Y, Cb, and Cr color components. Each array has one entry for each image block. Each entry itself is a 1024-element one-dimensional array. The elements of each one-dimensional array are the wavelet coefficients. The wavelet coefficients are signed fixed-point numbers with six fractional bits.

10.6.1 Sequence of operations

To reconstruct the image from the coefficients, the following steps must be performed:

1. Reordering coefficients. For each color component, each of the 1024-element coefficient arrays is converted into a 32 x 32 coefficient array. These square coefficient arrays are embedded into a larger reconstruction array whose size is the size of the image.
2. Inverse wavelet transform. For each color component, the inverse wavelet transform is applied to the larger reconstruction array. The inverse transform is applied at progressively finer scales, and within each scale in each of the two directions, first vertically, then horizontally.
3. Precision reduction. For each color component, the data values in the reconstruction array are reduced to eight bits. Conversion to RGB color space. For color images, the eight-bit values of each pixel in the YCbCr color space are converted to the corresponding eight-bit values in the RGB color space.

10.6.2 Coordinate system

For indexing the blocks within a color component, the origin (0, 0) is at the lower left corner of the image. Horizontal indices increase rightward, and vertical indices increase upward.

For indexing the coefficients within a 32 x 32 block coefficient array, the origin (0, 0) is at the lower left corner of the block. Horizontal indices increase rightward, and vertical indices increase upward.

For indexing the coefficients and color values within the image in the reconstruction array, the origin (0, 0) is at the lower left corner of the image. Horizontal indices increase rightward, and vertical indices increase upward.

When the array of coefficients for a block is embedded into the reconstruction array, the origin of the block coefficient array is placed into the lower left corner of the section of the reconstruction array that corresponds to the block.

10.6.3 Reordering coefficients

Within each color component, the coefficients in each block are moved from a 1024-element linear array into a 32 x 32 square array. The square array from each block is embedded in a reconstruction array the size of the full image.

The mapping from indices in the linear array to indices in the square array is as follows: if the ten bits of the index in the linear array are $\mathbf{b_9b_8b_7b_6b_5b_4b_3b_2b_1b_0}$, $\mathbf{b_9}$ being the most significant bit of the index, then the bits of the row index of the square array are $\mathbf{b_1b_3b_5b_7b_9}$, $\mathbf{b_1}$ being the most significant bit of the row index, and the bits of the column index of the square array $\mathbf{b_0b_2b_4b_6b_8}$, $\mathbf{b_0}$ being the most significant bit of the column index.

If the number of rows in the image is not a multiple of 32, then blocks along the top edge of the image have fewer than 32 rows. If the number of columns in the image is not a multiple of 32, then blocks along the right edge of the image have fewer than 32 columns. For all such blocks, all coefficients are coded; however, coefficients that fall outside the

boundary of the image after the coefficient mapping described above are never used, regardless of their value.

10.6.4 Inverse wavelet transform

The inverse transformation from wavelet coefficients to color values is done independently for the three color components. Within a color component the transformation is done for a decreasing sequence of scale parameters s. For a given scale parameter *s*, the transformation is done first for columns, then for rows. Within a column or row, the transformation is done in two passes, a lifting pass and then a prediction pass.

The scale parameter's initial value is $s = 16$. After the vertical and horizontal transformations have been done with a given value of s, the value of s is divided by 2 and the next pair of transformations is performed. After the vertical and horizontal transformations have been performed with $s = 1$, the inverse wavelet transform for the color component is complete.

The pair of transformations for a given value of *s* involve only rows and columns whose indices are multiples of *s*. The vertical transformation involves transforming the coefficients in column 0 whose row indices are multiples of s, then repeating the transformation for all other columns whose column indices are multiples of s. Some of the coefficients transformed by the vertical transformation will already have been transformed during earlier iterations with larger values of the scale parameter s.

The horizontal transformation involves transforming the coefficients in row 0 whose column indices are multiples of s, then repeating the transformation for all other rows whose row indices are multiples of s. The coefficients transformed by the horizontal transformation will have been transformed by the vertical transformation during the first pass for the current scale parameter s. Some of the coefficients transformed by the horizontal transformation will already have been transformed during earlier iterations with larger values of the scale parameter s.

To transform one column or row of coefficients:

1. If transforming a column, select the coefficients in the current column that come from rows whose indices are multiples of *s*. The coefficient from the row whose index is *ks* is referred to as c_k. The largest value of *k* is referred to as k_{max}.
2. If transforming a row, select the coefficients in the current row that come from columns whose indices are multiples of s. The coefficient from the row whose index is *ks* is referred to as c_k. The largest value of *k* is referred to as k_{max}.
3. Lifting. For each even-numbered subscript *k*, $0 \le k \le k_{max}$, replace coefficient c_k with

$$c_k - \left\lfloor \frac{9(c_{k-1} + c_{k+1}) - (c_{k-3} + c_{k+3}) + 16}{32} \right\rfloor$$

Special cases: If $k - 3 < 0$, use $c_{k-3} = 0$. If $k - 1 < 0$, use $c_{k-1} = 0$. If $k + 1 > k_{max}$, use $c_{k+1} = 0$. If $k + 3 > k_{max}$, use $c_{k+3} = 0$

3. Prediction. For each odd-numbered subscript *k*, $0 \le k \le k_{max}$, replace coefficient c_k

as follows:

a) If k-3≥ 0 and k+3 ≤ k_{max}, replace c_k with

$$c_k - \left\lfloor \frac{9(c_{k-1} + c_{k+1}) - (c_{k-3} + c_{k+3}) + 16}{32} \right\rfloor$$

b) Otherwise if k+1 ≤ k_{max}, replace c_k with

$$c_k + \left\lfloor \frac{c_{k-1} + c_{k+1} + 1}{2} \right\rfloor$$

c) Otherwise, replace c_k with $c_k + c_{k-1}$

10.6.5 Precision reduction for color image data

After the inverse transformation, a color value in the reconstruction array for each color component is a signed fixed-point value with 6 fractional bits. This value is to be rounded to the nearest integer V. Then if V < -128, V is set to -128. If V≥ 128, V is set to 127. Finally, in the luminance (Y) color component only, V is increased by 128.

10.6.6 Precision reduction for grayscale image data

After the inverse transformation, a grayscale value in the reconstruction array is a signed fixed-point value with 6 fractional bits. This value is to be rounded to the nearest integer V. Then if V<-128, V is set to -128. If V≥128, V is set to 127. Finally, V is replaced by 127- V.

10.6.7 Conversion from YC_bC_r color space to RGB color space

For a color image, each pixel has a value in each of the color component reconstruction buffers. To convert a pixel's YCbCr values to the corresponding RGB values, perform the following transformation:

$R = Y + (3/2)C_r$

$G = Y - (1/4)C_b - (3/4)C_r$

$B = Y + (7/4)C_b$

11 Appendix 2: JB2 coding.

11.1 General considerations.

Selection layer coding is used in Compound DJVU Images. In such images, there are three layers. The foreground layer is coded in one FG44 chunk, and is rendered as described in Appendix 1. The background layer is coded in one or more BG44 chunks, and is rendered as described in Appendix 1. The selection layer is coded using one Sjbz chunk. Black pixels in the selection layer specify those pixels that are to be rendered using the foreground color. All other pixels are to be rendered using the background color.

Black and white coding is used in Bi-level DJVU Images. In such images, there are three layers. The foreground layer is black. The background layer is white. The selection layer

is coded using one Sjbz chunk. The selection layer specifies those pixels that are to be rendered in black. All other pixels are to be rendered in white.

An Sjbz chunk contains a single arithmetically encoded data stream, coded using the Z′-Coder (Appendix 3). All data, including headers and record types, is coded in this arithmetically coded stream.

11.2 Arithmetic coding

The arithmetically coded data in an Sjbz chunk consists logically of records. The record types are listed in Table 6, and described in Section 8.4. The records consist of fields. The fields present for records of each record type are listed in Table 6. The fields within a record are coded in the order listed in Table 6 for records of that type. Details of the coding for each field appear in Section 8.5.

A field may contain one or more data elements. The data elements consist of flags, pixel colors, and integers. Because of the nature of arithmetic coding, the records, fields, and data elements are not of fixed sizes, and do not necessarily begin on bit boundaries within the data stream.

Flags are binary decisions, each coded using the Z′-Coder with a particular context. There are two different contexts for flags, the eventual image refinement context and the offset type context.

Pixel colors are binary decisions, coded using the Z′-Coder with a particular context. For pixel colors, there are 3072 different contexts. There are 1024 contexts used for direct coding of bitmaps; these correspond to the $2^{10} = 1024$ different combinations of values that the pixels in the direct coding template can assume. There are 2048 contexts used for refinement coding of bitmaps; these correspond to the $2^{11} = 2048$ different combinations of values that the pixels in the refinement coding template can assume.

Integers are coded using the multivalue extension to the Z′-Coder, described below. There are 15 contexts for coding multivalued integers, as described in Table 7.

11.2.1 Initialization of the Z′-Coder

All Z′-Coder contexts are initialized to the value 0. This applies both to contexts used to encode single bit values, including pixel colors, and to contexts that are part of an integer context used by the multivalue extension to the Z′-Coder.

11.2.2 The multivalue extension to the Z′-Coder for coding of numeric data

Quantities that can take on multiple values are coded as integers using the multivalue extension to the Z′-Coder. This extension of the Z′-Coder allows all data in the bitstream to be coded using the same coder, the Z′-Coder. There are 15 integer contexts, specified in Table 7. A single integer context includes a number of binary contexts.

One integer context consists of a binary decision tree. See Figure 1 for an example of part of such a tree. The root node of the tree corresponds to the decision about the sign of the number n being decoded. Each of the two sub trees under the root corresponds to a set of decisions that eventually identify a range in which n lies. The sub trees under the nodes

corresponding to identified ranges are complete binary trees that identify the exact value of n.

Each node of the binary decision tree for an integer context maintains its own binary probability estimation context for the Z´-Coder. The trees for different integer contexts are completely independent. Thus each node of a tree contains probability information conditioned on a conditioning context. The conditioning context consists of both the type of value being coded (i.e., the selection of the integer context), and of the values of the decisions coded so far when encoding the current integer.

11.2.3 Record Types

Record type coded value	Record type	Fields coded
0	Start of image	Record type Image size Eventual image refinement flag
1	New symbol, add to image and library	Record type Absolute symbol size Bitmap by direct coding Location relative to a previous symbol
2	New symbol, add to library only	Record type Absolute symbol size Bitmap by direct coding
3	New symbol, add to image only	Record type Absolute symbol size Bitmap by direct coding Location relative to a previous symbol
4	Matched symbol with refinement, add to image and library	Record type Index of matching symbol in bitmap library Relative symbol size Bitmap by refinement coding Location relative to a previous symbol
5	Matched symbol with refinement, add to library only	Record type Index of matching symbol in bitmap library Relative symbol size Bitmap by refinement coding
6	Matched symbol with refinement, add to image only	Record type Index of matching symbol in bitmap library Relative symbol size Bitmap by refinement coding Location relative to a previous symbol
7	Matched symbol, copy to image without refinement	Record type Index of matching symbol in bitmap library Location relative to a previous symbol
8	Non-symbol data	Record type Absolute symbol size Bitmap by direct coding

		Absolute location
9	Shared dictionary or numcoder reset	Record type Shared dictionary size
10	Comment	Record type Comment length Comment data
11	End of data	Record type

Table 6: Record types and fields coded for each record type

11.2.4 Fields / Contexts

Context name	Integer data coded using this context
Record type	record type
Image size	image height and image width
matching symbol index	index within the symbol library of the symbol matching the
symbol width	current symbol
symbol height	number of pixels in the width of the current symbol
symbol width difference	number of pixels in the height of the current symbol
symbol height difference	number of pixels that must be added to the width of the matching symbol to obtain the width of the current symbol
symbol column number	number of pixels that must be added to the height of the matching symbol to obtain the height of the current symbol column number of the absolute location of the left edge of the current symbol (leftmost column of the image is column number 1)
symbol row number	row number of the absolute location of the top edge of the current symbol (bottom row of the image is row number 1)
same line column offset	number of pixels that must be added to the column number of the right edge of the previous symbol on the current text line to obtain the column number of the left edge of the current symbol
same line row offset	number of pixels that must be added to the row number of the current baseline on the current text line to obtain the row number of the bottom edge of the current symbol
new line column offset	number of pixels that must be added to the column number of the left edge of the first symbol on the current text line to obtain the column number of the left edge of the current symbol
new line row offset	number of pixels that must be added to the row number of the bottom edge of the first symbol on the current text line to obtain the row number of the top edge of the current symbol

comment length	the number of octets in the current comment
comment octet	one octet in the current comment
dictionary size	Number of shapes in the shared dictionary.

Table 7: Multivalued integer contexts for arithmetic coding

11.2.5 Coding Phases

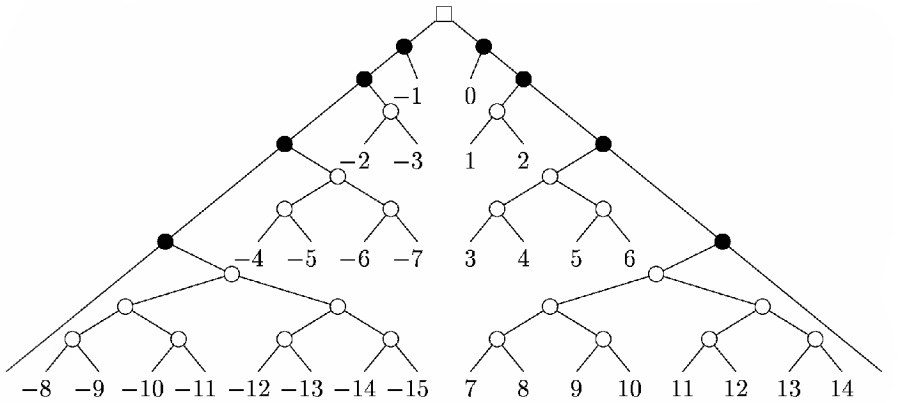


Figure 1: Part of the coding tree for multisymbol arithmetic coding. Each internal node represents one context with its own probability information, to be used by the Z′-Coder. The square node at the root of the tree represents the Phase 1 decision, whether the integer n being coded is negative. The filled circles are the Phase 2 nodes, moving down the tree in ever-increasing ranges. The open circles represent Phase 3 decisions, traversing a complete binary subtree to reach the specific value of n. A decoded value of 0 indicates a left branch in this tree. A decoded value of 1 indicates a right branch.

This method allows high compression efficiency by allowing the coder to adapt to the statistics of the data. In effect, the binary probability information stored collectively in the nodes of the decision tree closely approximates the probability distribution of the underlying multi-valued integer.

The allowable range of values for n is always specified. The smallest value that n could possibly take is denoted by 1. The largest number that n could possibly take is denoted by h. When 1 and h are equal, n is equal to both of them, and no Z′-Coder decoding is performed.

The decoder maintains a non-negative intermediate value v, defined as follows:

$$v = \begin{cases} |n| & \text{if } n \geq 0 \\ |n| - 1 & \text{if } n < 0. \end{cases}$$

At the end of the process of decoding an integer, v is converted to n, the value of the decoded integer.

The value of an integer is coded by making a sequence of binary decisions, each one narrowing the set of possible values that the integer can possibly take. The decisions are based on traversing a binary decision tree to one of its leaves. Note: although the tree conceptually has a large number of nodes, it is possible in an implementation to allocate memory only for those nodes actually traversed. Decoding proceeds in four phases.

11.2.5.1 Phase 1.

Phase 1 determines the sign of n. A value of 0 returned by the Z′-Coder means that n < 0. A value of 1 returned by the Z′-Coder means that n _> 0.

11.2.5.2 Phase 2.

Phase 2 determines a range of possible values for v. The Z′-Coder is invoked repeatedly to answer the question "Is the value of v in the range being tested?" The sequence of ranges tested is given in Table 8. A value of 0 returned by the Z′-Coder means that v is not in the specified range, and the next range in the sequence must be tested. A value of 1 returned by the Z′-Coder means that v is in the specified range, and decoding is to proceed to Phase 3.

0
1-2
3-6
7-14
15-30
31-62
63-126
127-254
255-510
511-1022
1023-2046
2047-4094
4095-8190
8191-16382
16383-32766
32767-65534
65535-131070
131071-262142

Table 8: Sequence of ranges in which v may fall.

11.2.5.3 Phase 3.

Phase 3 consists of determining the exact value of v within the range determined in Phase 2. If Phase 2 determined that v -- 0, then Phase 3 is skipped. Otherwise, since the size of the range is a power of 2, the corresponding subtree is a complete binary tree. The sequence of coding decisions is based directly on traversing the binary tree. At each node,

0 returned by the Z′-Coder means left branch (smaller values of v) and I means right branch (larger values of v). The bits returned by the Z′-Coder during Phase 3 are the bits of v, most significant bit first.

11.2.5.4 Phase 4.

In Phase 4, the unsigned value v is converted to n, the signed value to

be returned, as follows:

$$n = \begin{cases} v & \text{if } n \text{ is non-negative, as determined in Phase 1;} \\ -v-1 & \text{if } n \text{ is negative, as determined in Phase 1.} \end{cases}$$

In any of the phases, if the input values of 1 and h (the range of allowable values) predetermine any decision, then the coding for that decision is not performed; the predetermined decision is assumed.

Each type of integer has its own set of binary contexts. Thus the probability information will reflect the underlying probability distribution of the particular type of integer. The Z′-Coder probability state indices of all the binary nodes are initialized to 0.

11.3 Image reconstruction

Records in an Sjbz chunk are interpreted in the order in which they appear. A start of data record specifies the dimensions of the image. An image refinement data record indicates the end of the Sjbz chunk. An end of data record indicates the end of the Sjbz chunk. A comment record contains uninterpreted data.

A record identified by any other record type describes one bitmap. The model used in DjVu for the selection layer is based on symbol-based coding. Bitmaps are placed into the reconstructed image as follows: The image is initially entirely white. When a bitmap is placed into the image, the pixels that are black in the current symbol become black at the appropriate position in the reconstructed image. Once a pixel in the reconstructed image becomes black, it remains black.

Because symbols in document images are often similar to each other, it is often possible to obtain more efficient coding by making use of previously coded symbols. As symbols are decoded, their bitmaps may be placed into a symbol bitmap library. There is exactly one symbol bitmap library. Once a symbol has been placed into the symbol bitmap library, later records may cause copies of the symbol to be placed into the image, or may define a new bitmap by refining the bitmap in the library.

Depending on the record type, the symbol bitmap may be described by direct coding, by refinement coding, or by a copy operation. In direct coding, all pixels of the bitmap are coded directly, without reference to any other bitmap. In refinement coding, all pixels of the bitmap are also coded directly, but a bitmap in the library is used to make the coding more efficient. In a copy operation, the pixels of the bitmap are the same as the pixels of a bitmap in the library.

Depending on the record type, the bitmap may or may not be placed into the image. If the bitmap is placed into the image, then depending on the record type, it may be placed either at an absolute location or at a location relative to a previously placed bitmap.

Depending on the record type, the bitmap may or may not be placed into the symbol bitmap library. The first symbol placed into the library has index 0. Subsequent symbols are assigned consecutive integer indices.

The pixels of the reconstructed image are arranged in a rectangular coordinate system. For the pixel in the lower left corner of the image, the column number is i and the row number is 1. All coordinates refer to the pixels themselves, not to the edges between pixels.

11.4 Records

Records in Sjbz chunks have the following interpretations.

11.4.1 Start of image

A start of image record is the first record in an Sjbz chunk. the image. It specifies the dimensions of the image

11.4.2 New symbol, add to image and library

A new symbol, add to image and library record specifies the bitmap of a symbol that is coded directly and placed into the reconstructed image and into the symbol bitmap library.

11.4.3 New symbol, add to library only

A new symbol, add to library only record specifies the bitmap of a symbol that is coded directly and placed into the symbol bitmap library but not into the image.

11.4.4 New symbol, add to image only

A new symbol, add to image only record specifies the bitmap of a symbol that is coded directly and placed into the reconstructed image but not into the symbol bitmap library.

11.4.5 Matched symbol with refinement, add to image and library

A matched symbol with refinement, add to image and library record specifies the bitmap of a symbol that is coded by refinement of a symbol in the symbol bitmap library and placed into the reconstructed image and into the symbol bitmap library.

11.4.6 Matched symbol with refinement, add to library only

A matched symbol with refinement, add to library only record specifies the bitmap of a symbol that is coded by refinement of a symbol in the symbol bitmap library and placed into the symbol bitmap library, but not into the reconstructed image.

11.4.7 Matched symbol with refinement, add to image only

A matched symbol with refinement, add to image only record specifies the bitmap of a symbol that is coded by refinement of a symbol in the symbol bitmap library and placed into the reconstructed image, but not into the symbol bitmap library.

11.4.8 Matched symbol, copy to image without refinement

A matched symbol, copy to image without refinement record specifies the location at which the bitmap of a symbol in the symbol bitmap library is to be placed into the reconstructed image.

11.4.9 Non-symbol data

A non-symbol data record specifies a direct coded bitmap to be placed at an absolute location in the reconstructed image. A bitmap of non-symbol data is not placed into the symbol bitmap library.

11.4.10 Shared dictionary or reset

This record is overloaded and its meaning depends on its context. If the record occurs before a START_OF_DATA, then this ia a REQUIRED_DICT records. If the record occurs after a START_OF_DATA record then this is a NUMCODER_RESET record.

11.4.10.1 Shared Shape Dictionaries

Starting with version 21, the JB2 format provides support for sharing symbol definitions between the pages of a document. To achieve this objective, the JB2 image data chunk must be able to address symbols defined elsewhere by a JB2 dictionary data chunk shared by all the pages of a document.

A #REQUIRED_DICT_OR_RESET# (9) record type can appear *before* the #START_OF_DATA# (0) record. The record type field is followed by a single number arithmetically encoded using the sixteenth "dictionary size" context. This record appears when the JB2 data chunk requires symbols encoded in a separate JB2 dictionary data chunk. The number (the *dictionary size*) indicates how many symbols should have been defined by the JB2 dictionary data chunk. The decoder should simply load these symbols in the symbol library and proceed as usual. New symbols potentially defined by the subsequent JB2 image data records will therefore be numbered with integers greater or equal than the dictionary size.

11.4.10.2 Numcoder Reset

The encoding of numbers potentially uses an unbounded number of binary coding contexts. These contexts are normally allocated when they are used for the first time (see ICFDD informative note, page 27).

Starting with version 21, a #REQUIRED_DICT_OR_RESET# (9) record type can appear *after* the #START_OF_DATA# (0) record. The decoder should proceed with the next record after *clearing all binary contexts used for coding numbers*. This operation implies that all binary contexts previously allocated for coding numbers can be deallocated.

Starting with version 21, the JB2 encoder should insert a #REQUIRED_DICT_OR_RESET# record type whenever the number of these allocated binary contexts exceeds #20000#. Only very large documents ever reach such a large number of allocated binary contexts (e.g large maps). Hardware implementation however can benefit greatly from a hard bound on the total number of binary coding

contets. Old JB2 decoders will treat this record type as an #END_OF_DATA# record and cleanly stop decoding (see ICFDD page 30, Image refinement data).

11.4.10.3 Record Types in a Shared Dictionary

The shared JB2 dictionary data format is a pure subset of the JB2 image data format:

- REQUIRED_DICT (9)
- START_OF_DATA (0)
- NEW_MARK_LIBRARY_ONLY (2)
- MATCHED_REFINE_LIBRARY_ONLY (5)
- NUMCODER_RESET (9)
- PRESERVED_COMMENT (10)
- END_OF_DATA (11)

Note that each shared dictionary can itself include another shared dictionary.

The JB2 dictionary data is usually located in an *Djbz* chunk. Each page *FORM:DJVU* may directly contain a *Djbz* chunk, or may indirectly point to such a chunk using an *INCL* chunk (see *Multipage DjVu documents.*)

11.4.11 Comment

A comment record contains data whose interpretation is not specified by the standard.

11.4.12 End of data

An end of data record is the last record of an Sjbz chunk.

11.5 Fields

The following fields are coded in records of types specified in Table 6 and in Section 8.4.

11.5.1 Record type

The record type is coded by the multivalue extension to the Z′-Coder using the record type context. The range of allowable record types is from 0 to 11. The coded values are specified in the first column of Table 6.

11.5.2 Image size

The width and height of the image are coded by the multivalue extension to the Z′-Coder using the image size context. The width is coded first, then the height. The range of allowable values is from 0 to 262142. The width and height of a Compound DJVU Image or Bilevel DJVU Image must be the same as the width and height of the image specified in the INFO chunk.

11.5.3 Eventual image refinement flag

The EVENTUAL IMAGE REFINEMENT flag is coded once, in the start of image record, to notify the decoder whether image refinement data will eventually be provided. It is a binary value, coded by the Z′-Coder using the eventual image refinement context.

The coded value 1 means TRUE and the coded value 0 means FALSE. Note: This flag is always FALSE in the current version of the standard, but it may be TRUE in later versions.

11.5.4 Index of matching symbol in bitmap library

The index of the matching symbol in the bitmap library is coded with the multivalue extension to the Z´-Coder, using the matching symbol index context. The range of allowable values is from 0 to one less than the number of symbols currently in the bitmap library.

11.5.5 Absolute symbol size

The width of a symbol is coded by the multivalue extension to the Z´-Coder, using the symbol width context. Then the height of a symbol is coded by the multivalue extension to the Z´-Coder, using the symbol height context. The range of allowable values for both of these data elements is from 0 to 262142.

11.5.6 Relative symbol size

The signed differences between the width and height of the current symbol and the width and height respectively of the matching symbol are coded by the multivalue extension to the Z´-Coder using the symbol width difference context for the width and using the symbol height difference context for the height. The width difference is coded first, then the height difference. The coded signed difference is added to the width or height of the matching symbol to obtain the width or height respectively of the current symbol. The range of allowable values for both of these data elements is -262143 to 262142.

11.5.7 Absolute location

The horizontal and vertical positions of the upper left corner of the bitmap are coded by the multivalue extension to the Z´-Coder using the symbol column number context for the horizontal position and the symbol row number context for the vertical position. The horizontal position is coded first, then the vertical position. The range of allowable values for the horizontal position is from i to the number of pixels in the width of the image. The range of allowable values for the vertical position is from i to number of pixels in the height of the image.

11.5.8 Location relative to a previous symbol

The OFFSET TYPE flag is coded by the Z´-Coder using the offset type context. It indicates the reference symbol for coding the offset of the location of the current symbol. The coded value 1 means FIRST, which means that the location of the current symbol is being specified relative to the first symbol on the current text line. The value 0 means PREVIOUS, which means that the location of the current symbol is being specified relative to the most recently coded symbol on the current text line.

If the OFFSET TYPE flag is FIRST,then the reference symbol is the first symbol on the current text line. The horizontal offset is the signed difference between the left edge of the current symbol and the left edge of the reference symbol. It is coded with the

multivalue extension to the Z′-Coder using the new line column offset context. The coded signed difference is added to the column number of the left edge of the reference symbol to obtain the column number of the left edge of the current symbol. The vertical offset is the signed difference between the top edge of the current symbol and the bottom edge of the reference symbol. It is coded by the multivalue extension to the Z′-Coder using the new line row offset context. The coded signed difference is added to the row number of the bottom of the reference symbol to obtain the row number of the top edge of the current symbol. The current symbol is then treated as the first symbol of a new text line. In this case, the horizontal offset is coded first, then the vertical offset.

If the OFFSET TYPE flag is PREVIOUS, then the reference symbol is the most recently coded symbol on the current text line. The horizontal offset is the signed difference between the left edge of the current symbol and the right edge of the reference symbol. It is coded by the multivalue extension to the Z′-Coder using the same line column offset context. The coded signed difference is added to the column number of the right edge of the reference symbol to obtain the column number of the left edge of the current symbol. The vertical offset is the signed difference between the bottom edge of the current symbol and the current baseline. The current baseline is the median of the bottom edges of the three most recently coded symbols on the current line, if there are at least three symbols on the current line. If there are fewer than three previously coded symbols on the current line, the baseline is the bottom edge of the first symbol on the current line. The vertical offset is coded by the multivalue extension to the Z′-Coder using the same line row offset context. The coded signed difference is added to the row number of the current baseline to obtain the row number of the bottom edge of the current symbol. In this case, the horizontal offset is coded first, then the vertical offset.

The first symbol in the image is coded as if it were relative to the first symbol on the current text line. The pixel in the upper left corner of the image is taken to be the bottom left corner of this "first symbol." Then the first symbol in the image is treated as the first symbol of a new text line.

11.5.9 Bitmap by direct coding

Non-symbol bitmaps and symbol bitmaps with no sufficiently closely matching symbol in the symbol library are coded directly. A directly coded bitmap is coded by repeated applications of the Z′-Coder to the pixels of the bitmap left to right across the rows, starting with the top row. When one row has been coded, the next lower row is coded. Each pixel is coded by the Z′-Coder using an appropriate context based on the values of 10 previously coded pixels. A coded value of 1 means the pixel is BLACK. A coded value of 0 means the pixel is WHITE. The colors of the pixels numbered 1 through 10 in Figure 2, taken collectively,

form a 10-bit value. Each of these values is an index into a table of 1024 different direct coded bitmap contexts. The pixel labeled P in Figure 2 is coded using the context indexed by the collective values of the other 10 numbered pixels in the template.

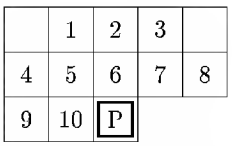


Figure 2: Template for direct coding

Pixels outside the bounding box of the bitmap being coded are considered to be white.

11.5.10 Bitmap by refinement coding

Some bitmaps are coded by making use of data from another bitmap; this process is called refinement coding. Matched symbols other than those to be copied are coded using refinement coding.

A bitmap coded by refinement coding is coded by repeated applications of the Z′-Coder to the pixels of the bitmap left to right across the rows. When one row has been coded, the next lower row is coded. Each pixel is coded by the Z′-Coder using an appropriate context based on the values of 4 previously coded pixels from the bitmap being coded and 7 pixels from the matching bitmap. (The pixels numbered 1 through 4 in Figure 3 are from the current symbol; the pixels numbered 5 through 11 are from the matching symbol.) A coded value of 1 means the pixel is BLACK. A coded value of 0 means the pixel is WHITE. The colors of the pixels numbered 1 through 11 in Figure 3, taken collectively, form an 11-bit value. Each of these values is an index into a table of 2048 different refinement coded bitmap contexts. The pixel labeled P in Figure 3 is coded using the context indexed by the collective values of the 11 numbered pixels in the template. Pixel 7 is in the position in the matching symbol that corresponds to the position of pixel P in the current symbol when the two symbols are aligned.

Alignment of the current bitmap and the matching bitmap proceeds as follows. For matched symbols, the current symbol and the matching symbol are aligned according to the geometric centers of their bounding rectangles. If the number of columns or rows is even, the geometric center falls between two columns or rows, respectively. In this case, the leftmost of the two central columns or the lowermost of the two central rows is considered to be the center column or row, respectively.

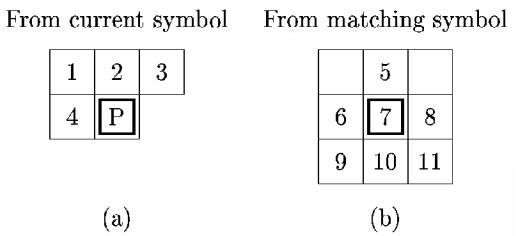


Figure 3: Template for refinement coding. (a) Pixels from symbol being coded from matching symbol. (b) Pixels from matching symbol.

It is possible for the current symbol to have empty edge rows or columns. These empty rows and columns are coded, and are included in the bounding rectangle. For symbols added to the library, the symbol is added to the library after if has been placed into the

image. Any empty edge rows and columns are removed before the symbol is added to the library.

11.5.11 Comment length

The comment length is the number of octets in the comment. It is coded by the multivalue extension to the Z´-Coder using the comment length context. The range of allowable values for the comment length is from 0 to 262142.

11.5.12 Comment data

Comment data consists of the individual octets of the comment. The number of octets in the comment is given by the comment length field. Each of the octets is coded using the multivalue extension to the Z´-Coder using the comment octet context. The range of allowable values for each octet is from 0 to 255.

12 Appendix 3: Z´coding.

The Z´-Coder is an approximate binary arithmetic coder. Decoding proceeds as follows.

See also file ZPCodec.h and ZPCodec.cpp in DjVuLibre.

12.1 Registers and data storage

In Figure 1 and Figure 2, the values of variables A, C, D, and Z are stored in registers of at least 16 bits each. A and C retain their values between invocations of the Z´-Coder. The values of D and Z are recomputed during each invocation of the Z´-Coder. Note: *If register overflow can be ignored, storing variables A and C in registers of exactly 16 bits allows a simplification of lines 11, 12, 16, and 17 of Figure 1 and lines 8, 9, 12, and 13 of Figure 2.*

At the beginning of a chunk, the values of A and C are reinitialized. When the decoder is decoding a chunk, it may require more bits than are present within the chunk's data. In this case, all additional required bits are to be assumed by the decoder to be 1. If there are excess bits at the end of a chunk, they are ignored.

K is conceptually an array with a single 8-bit entry for each binary decision context. (Inpractice, K consists of a number of individual values, arrays, and tree nodes, but each one has a specific address and a single 8-bit value at any time.) This array is indexed by the value of i, which is the input to the decoder. K(i) is the current value of the probability state index for context i. K(i) may be updated as part of the decoding process.

In pass-through mode, the decoder is invoked with no input argument. No context is involved.

B is the 1-bit value returned by the decoder.

The Z´-Coder is state-based. Decoding is governed by 4 fixed tables, given in Table 9. The tables are indexed by K(i), the probability state index for the current context. All probability state indices are initialized to 0. That is, at the beginning of coding, for all i, K(i) = 0. These values are not reinitialized at the beginning of chunks after the first.

The more probable symbol is denoted by MPS. The MPS is 1 if the probability state index is an odd integer, and 0 if the probability state index is an even integer. The less probable symbol is denoted by LPS. The LPS is 0 if the probability state index is an odd integer, and 1 if the probability state index is an even integer.

Δ_k is the amount by which the current arithmetic coding interval is reduced if the decoded symbol is the MPS. θ_k is the threshold above which an MPS triggers a probability state update. μ_k is the next probability state index for context k after an MPS triggers a probability state index update. An LPS always triggers a probability state index update. λ_k is the next probability state index for context k after an LPS.

12.2 Initialization

Initially, A is set to 0x0000. Two octets are read from the input data stream into the lowest 16 bits of C. If the bits of C are numbered such that bit 15 is the most significant bit and bit 0 is the least significant bit, then the first input octet is stored in bits 15 through 8, and the second input octet is stored in bits 7 through 0.

12.3 Decoding

Figure 1 shows the steps involved in decoding a single binary decision. The input to the decoder is the index i of the appropriate context for the binary decision being decoded. The output from the decoder is a single bit B.

12.3.1 Notes on specific lines of Figure 1

Line 2. The division is a right shift, discarding the two least significant bits.

Lines 4-8. These lines are executed when the decoded bit is the MPS.

Line 5. This line determines the value of MPS from the odd/even parity of the probability state index.

Line 6. Sometimes an MPS event triggers an update of the probability state index, based on the value of θ_k. Note that when the probability state index $k = 0$ or $k \geq 83$, $\theta_k = 0$, so an MPS will trigger an update of the probability state index. All probability state indices are initialized to 0, but the first coded decision for a context causes the index to become larger than 83. When $k = 0$ or $k \geq 83$, the probability estimate for the context is in its early estimation phase. When $0 \leq k \leq 83$, the probability estimate for the context is in its steady state phase, which it never leaves.

Lines 9-14. These lines are executed when the decoded bit is the LPS.

Line 10. This line determines the value of LPS from the odd/even parity of the probability state index.

Line 13. An LPS always triggers an update of the probability state index.

Lines 15-18. When the values in the registers are too large, they must be renormalized.

Lines 1ti-17. A+A and C+C may be accomplished by left shifts, leaving the least significant bit equal to 0.

Line 17. The least significant bit of C is filled with the next bit from the input stream.

Bits are taken from each octet in the input stream most significant bit first.

```
1   Z := A + Δ_K(i)
2   D := 0x6000 + (Z + A)/4
3   if (Z > D) { Z := D}
4   if (C > Z) {
5       B := K(i) (mod 2)
6       if (A ≥ θ_K(i)) { K(i) = μ_K(i)}
7       A := Z
8   }
9   else {
10      B := 1 − (K(i) (mod 2))
11      A := A + 0x10000 − Z
12      C := C + 0x10000 − Z
13      K(i) = λ_K(i)
14  }
15  while (A ≥ 0x8000) {
16      A := A + A − 0x10000
17      C := C + C − 0x10000 + next code bit
18  }
19  return B
```

Figure 1: Decoder for Z′-Coder

12.4 Pass-through decoding

Figure 2 shows the steps involved in decoding a single binary decision using the Z′-Coder in pass-through mode. No input is required. No context is involved. No probability state index values are updated. The output from the decoder is the single bit B.

12.4.1 Notes on specific lines of Figure 2

Line 1. The division is a right shift, discarding the three least significant bits.

Lines 2-5. These lines are executed when the decoded bit is 0.

Lines 11-10. These lines are executed when the decoded bit is 1.

Lines 11-14. When the values in the registers are too large, they must be renormalized.

Lines 12-13. A+A and C+C may be accomplished by left shifts, leaving the least significant bit equal to 0.

Line 13. The least significant bit of C is filled with the next bit from the input stream. Bits are taken from each octet in the input stream most significant bit first.

```
1   Z := 0x8000 + (A + A + A)/8
2   if (C > Z) {
3       B := 0
4       A := Z
5   }
6   else {
7       B := 1
8       A := A + 0x10000 − Z
9       C := C + 0x10000 − Z
10  }
11  while (A ≥ 0x8000) {
12      A := A + A − 0x10000
13      C := C + C − 0x10000 + next code bit
14  }
15  return B
```

Figure 2: Decoder for Z′-Coder operating in pass-through mode.

k	Δ_k	θ_k	μ_k	λ_k
0	0x8000	0x0000	84	145
1	0x8000	0x0000	3	4
2	0x8000	0x0000	4	3
3	0x6BBD	0x10A5	5	1
4	0x6BBD	0x10A5	6	2
5	0x5D45	0x1F28	7	3
6	0x5D45	0x1F28	8	4
7	0x51B9	0x2BD3	9	5
8	0x51B9	0x2BD3	10	6
9	0x4813	0x36E3	11	7
10	0x4813	0x36E3	12	8
11	0x3FD5	0x408C	13	9
12	0x3FD5	0x408C	14	10
13	0x38B1	0x48FD	15	11
14	0x38B1	0x48FD	16	12
15	0x3275	0x505D	17	13
16	0x3275	0x505D	18	14
17	0x2CFD	0x56D0	19	15
18	0x2CFD	0x56D0	20	16
19	0x2825	0x5C71	21	17
20	0x2825	0x5C71	22	18
21	0x23AB	0x615B	23	19
22	0x23AB	0x615B	24	20
23	0x1F87	0x65A5	25	21
24	0x1F87	0x65A5	26	22
25	0x1BBB	0x6962	27	23
26	0x1BBB	0x6962	28	24
27	0x1845	0x6CA2	29	25
28	0x1845	0x6CA2	30	26
29	0x1523	0x6F74	31	27
30	0x1523	0x6F74	32	28
31	0x1253	0x71E6	33	29
32	0x1253	0x71E6	34	30
33	0x0FCF	0x7404	35	31

k	Δ_k	θ_k	μ_k	λ_k
34	0x0FCF	0x7404	36	32
35	0x0D95	0x75D6	37	33
36	0x0D95	0x75D6	38	34
37	0x0B9D	0x7768	39	35
38	0x0B9D	0x7768	40	36
39	0x09E3	0x78C2	41	37
40	0x09E3	0x78C2	42	38
41	0x0861	0x79EA	43	39
42	0x0861	0x79EA	44	40
43	0x0711	0x7AE7	45	41
44	0x0711	0x7AE7	46	42
45	0x05F1	0x7BBE	47	43
46	0x05F1	0x7BBE	48	44
47	0x04F9	0x7C75	49	45
48	0x04F9	0x7C75	50	46
49	0x0425	0x7DOF	51	47
50	0x0425	0x7DOF	52	48
51	0x0371	0x7D91	53	49
52	0x0371	0x7D91	54	50
53	0x02D9	0x7DFE	55	51
54	0x02D9	0x7DFE	56	52
55	0x0259	0x7E5A	57	53
56	0x0259	0x7E5A	58	54
57	0x01ED	0x7EA6	59	55
58	0x01ED	0x7EA6	60	56
59	0x0193	0x7EE6	61	57
60	0x0193	0x7EE6	62	58
61	0x0149	0x7F1A	63	59
62	0x0149	0x7F1A	64	60
63	0x010B	0x7F45	65	61
64	0x010B	0x7F45	66	62
65	0x00D5	0x7F6B	67	63
66	0x00D5	0x7F6B	68	64
67	0x00A5	0x7F8D	69	65

k	Δ_k	θ_k	μ_k	λ_k
68	0x00A5	0x7F8D	70	66
69	0x007B	0x7FAA	71	67
70	0x007B	0x7FAA	72	68
71	0x0057	0x7FC3	73	69
72	0x0057	0x7FC3	74	70
73	0x003B	0x7FD7	75	71
74	0x003B	0x7FD7	76	72
75	0x0023	0x7FE7	77	73
76	0x0023	0x7FE7	78	74
77	0x0013	0x7FF2	79	75
78	0x0013	0x7FF2	80	76
79	0x0007	0x7FFA	81	77
80	0x0007	0x7FFA	82	78
81	0x0001	0x7FFF	81	79
82	0x0001	0x7FFF	82	80
83	0x5695	0x0000	9	85
84	0x24EE	0x0000	86	226
85	0x8000	0x0000	5	6
86	0x0D30	0x0000	88	176
87	0x481A	0x0000	89	143
88	0x0481	0x0000	90	138
89	0x3579	0x0000	91	141
90	0x017A	0x0000	92	112
91	0x24EF	0x0000	93	135
92	0x007B	0x0000	94	104
93	0x1978	0x0000	95	133
94	0x0028	0x0000	96	100
95	0xl0CA	0x0000	97	129
96	0x000D	0x0000	82	98
97	0x0BSD	0x0000	99	127
98	0x0034	0x0000	76	72
99	0x0Y8A	0x0000	101	125
100	0x00A0	0x0000	70	102
101	0x050F	0x0000	103	123

k	Δ_k	θ_k	μ_k	λ_k
102	0x0117	0x0000	66	60
103	0x0358	0x0000	105	121
104	0x01EA	0x0000	106	110
105	0x0234	0x0000	107	119
106	0x0144	0x0000	66	108
107	0x0173	0x0000	109	117
108	0x0234	0x0000	60	54
109	0x00F5	0x0000	111	115
110	0x0353	0x0000	56	48
111	0x00A1	0x0000	69	113
112	0x05C5	0x0000	114	134
113	0x011A	0x0000	65	59
114	0x03CF	0x0000	116	132
115	0x01AA	0x0000	61	55
116	0x0285	0x0000	118	130
117	0x0286	0x0000	57	51
118	0x01AB	0x0000	120	128
119	0x03D3	0x0000	53	47
120	0x011A	0x0000	122	126
121	0x05C5	0x0000	49	41
122	0x00BA	0x0000	124	62
123	0x0SAD	0x0000	43	37
124	0x007A	0x0000	72	66
125	0x0CCC	0x0000	39	31
126	0x01EB	0x0000	60	54
127	0x1302	0x0000	33	25
128	0x02E6	0x0000	56	50
129	0x1B81	0x0000	29	131
130	0x045E	0x0000	52	46
131	0x24EF	0x0000	23	17
132	0x0690	0x0000	48	40
133	0x2865	0x0000	23	15
134	0x09DE	0x0000	42	136
135	0x3987	0x0000	137	7

k	Δ_k	θ_k	μ_k	λ_k
136	0x0DC8	0x0000	38	32
137	0x2C99	0x0000	21	139
138	0x10CA	0x0000	140	172
139	0x3B5F	0x0000	15	9
140	0x0B5D	0x0000	142	1?0
141	0x5695	0x0000	9	85
142	0x078A	0x0000	144	168
143	0x8000	0x0000	141	248
144	0x050F	0x0000	146	166
145	0x24EE	0x0000	147	247
146	0x0358	0x0000	148	164
147	0x0D30	0x0000	149	197
148	0x0234	0x0000	150	162
149	0x0481	0x0000	151	95
150	0x0173	0x0000	152	160
151	0x01?A	0x0000	153	173
152	0x00F5	0x0000	154	158
153	0x007B	0x0000	155	165
154	0x00A1	0x0000	70	156
155	0x0028	0x0000	157	161
156	0x011A	0x0000	66	60
157	0x000D	0x0000	81	159
158	0x01AA	0x0000	62	56
159	0x0034	0x0000	75	71
160	0x0286	0x0000	58	52
161	0x00A0	0x0000	69	163
162	0x03D3	0x0000	54	48
163	0x011?	0x0000	65	59
164	0x05C5	0x0000	50	42
165	0x01EA	0x0000	167	171
166	0x08AD	0x0000	44	38
167	0x0144	0x0000	65	169
168	0x0CCC	0x0000	40	32
169	0x0234	0x0000	59	53

k	Δ_k	θ_k	μ_k	λ_k
170	0x1302	0x0000	34	26
171	0x0353	0x0000	55	47
172	0x1B81	0x0000	30	174
173	0x05C5	0x0000	175	193
174	0x24EF	0x0000	24	18
175	0x03CF	0x0000	177	191
176	0x2B74	0x0000	178	222
177	0x0285	0x0000	179	189
178	0x201D	0x0000	180	218
179	0x01AB	0x0000	181	187
180	0x1715	0x0000	182	216
181	0x011A	0x0000	183	185
182	0x0FB7	0x0000	184	214
183	0x00BA	0x0000	69	61
184	0x0A67	0x0000	186	212
185	0x01EB	0x0000	59	53
186	0x06E7	0x0000	188	210
187	0x02E6	0x0000	55	49
188	0x0496	0x0000	190	208
189	0x045E	0x0000	51	45
190	0x030D	0x0000	192	206
191	0x0690	0x0000	47	39
192	0x0206	0x0000	194	204
193	0x09DE	0x0000	41	195
194	0x0155	0x0000	196	202
195	0x0D½8	0x0000	37	31
196	0x00E1	0x0000	198	200
197	0x2B74	0x0000	199	243
198	0x0094	0x0000	72	64
199	0x201D	0x0000	201	239
200	0x0188	0x0000	62	56
201	0x1715	0x0000	203	237
202	0x0252	0x0000	58	52
203	0x0FB7	0x0000	205	235

k	Δ_k	θ_k	μ_k	λ_k
204	0x0383	0x0000	54	48
205	0x0A67	0x0000	207	233
206	0x0547	0x0000	50	44
207	0x06E7	0x0000	209	231
208	0x07E2	0x0000	46	38
209	0x0496	0x0000	211	229
210	0x0BC0	0x0000	40	34
211	0x030D	0x0000	213	227
212	0x1178	0x0000	36	28
213	0x0206	0x0000	215	225
214	0x19DA	0x0000	30	22
215	0x0155	0x0000	217	223
216	0x24EF	0x0000	26	16
217	0x00E1	0x0000	219	221
218	0x320E	0x0000	20	220
219	0x0094	0x0000	71	63
220	0x432A	0x0000	14	8
221	0x0188	0x0000	61	55
222	0x447D	0x0000	14	224
223	0x0252	0x0000	57	51
224	0x5ECE	0x0000	8	2
225	0x0383	0x0000	53	47
226	0x8000	0x0000	228	87
227	0x0547	0x0000	49	43
228	0x481A	0x0000	230	246

k	Δ_k	θ_k	μ_k	λ_k
229	0x07E2	0x0000	45	37
230	0x3579	0x0000	232	244
231	0x0BC0	0x0000	39	33
232	0x24EF	0x0000	234	238
233	0x1178	0x0000	35	27
234	0x1978	0x0000	138	236
235	0x19DA	0x0000	29	21
236	0x2865	0x0000	24	16
237	0x24EF	0x0000	25	15
238	0x3987	0x0000	240	8
239	0x320E	0x0000	19	241
240	0x2C99	0x0000	22	242
241	0x432A	0x0000	13	7
242	0x3B5F	0x0000	16	10
243	0x447D	0x0000	13	245
244	0x5695	0x0000	10	2
245	0x5ECE	0x0000	7	1
246	0x8000	0x0000	244	83
247	0x8000	0x0000	249	250
248	0x5695	0x0000	10	2
249	0x481A	0x0000	89	143
250	0x481A	0x0000	230	246

13 Appendix 4: BZZ coding

Numerous streams in the DjVu file format are compressed using the general purpose compressor described here called BZZ. BZZ transforms the input data using the well documented Burrows-Wheeler Transform. However, the traditional "Move To Front" permutation table is augmented with a frequency estimation provided by the ZPCoder.

See also file BSByteStream.cpp.

13.1 Encoding

BZZ first takes as input a 24 bit integer as block size between 10K and 4M and an input stream (to be compressed). The stream is partitioned into blocks terminated with a

special <EOB> symbol. It is then transformed using the well-documented Burrows-Wheeler (BW or "block sorting") transform. Then, one block at a time, the block size and resulting output stream are then passed as input to the compressed using the Z′-Coder (Appendix 3).

13.2 Decoding

We describe the decoding algorithm by means of pseudo-code.

13.2.1 Decoding pseudo code

13.2.1.1 Z′-Coder utilities

```
// ------------------------------------
// decode one bit with the pass-thru mode

FUNCTION decode_passthru()
  // see section 12.4, Pass-through decoding
  ....

// ------------------------------------
// decode one bit using context i
// out of an array of 260 arithmetic contexts // initialized to zero
before decoding the first block.

FUNCTION decode( i:integer )
  // see section 12.4, Decoding
  ....

// ------------------------------------
// decode a b-bit integer using the pass-thru encoder

FUNCTION decode_raw( b:integer )
  var n: integer
  n := 1
  while n < (2^b)
      n := (n*2) + decode_passthru()
  return n - (2^b)

// ------------------------------------
// decode a b-bit integer using 2^b-1 arithmetic // contexts
k[cxoffset] to k[cxoffset+2^b-2]

FUNCTION decode_bin(cxoffset, b)
  var n: integer
  n := 1
  while n < (2^b)
      n := (n*2) + decode(cxoffset+n-1)
  return n - (2^b)
```

13.2.1.2 Decode a block

```
// ------------------------------------
// decode a data block from a bzz encoded file
```

```
FUNCTION decode_block

   var blocksize : integer
       markerpos : integer
       mtf       : array [0..255] of bytes
       data      : array [0..blocksize-1] of byte
       fshift    : integer
       fadd      : integer
       mtfno     : integer
       freq      : array [0..3] of integer
       posn      : array [0..blocksize-1] of integer
       posc      : array [0..blocksize-1] of byte
       count     : array [0..255] of integer
       last      : integer
       k         : integer

   /////// PHASE1 - arithmetic decoding

   // decode block size
   blocksize := decode_raw(24);

   // decode estimation speed
   fshift := 0
   if (decode_passthru())
      if (decode_passthru())
        fshift := 2;
      else
        fshift := 1;

   // fill mtf array
   for i:= 0 to 255
     mtf[i] = i

   // decode
   mtfno := 3
   markerpos := -1
   fadd := 4;
   for i:=0 to 3
      freq[i] = 0;

   for i := 0 to blocksize - 1
      var ctxid  : integer
          fc     : integer

      if (mtfno <= ctxid)
         ctxid = mtfno
      else
         ctxid := 2

      assert( ctxid=0 or ctxid=1 or ctxid=2 )

      if (decode(ctxid))
         mtfno := 0;
         data[i] := mtf[mtfno];
      else if (decode(ctxid+3))
         mtfno := 1;
         data[i] := mtf[mtfno];
```

```
else if (decode(6))
   mtfno := 2 + decode_bin(7, 1);
   data[i] := mtf[mtfno];
else if (decode(8))
   mtfno := 4 + decode_bin(9, 2);
   data[i] := mtf[mtfno];
else if (decode(12))
   mtfno := 8 + decode_bin(13, 3);
   data[i] := mtf[mtfno];
else if (decode(20))
   mtfno := 16 + decode_bin(21, 4);
   data[i] := mtf[mtfno];
else if (decode(36))
   mtfno := 32 + decode_bin(37, 5);
   data[i] := mtf[mtfno];
else if (decode(68))
   mtfno := 64 + decode_bin(69, 6);
   data[i] := mtf[mtfno];
else if (decode(132))
   mtfno := 128 + decode_bin(133, 7);
   data[i] := mtf[mtfno];
else
   mtfno := 256;   // EOB symbol
   data[i] := 0;
   markerpos := i;

if mtfno < 256
  // update frequencies
  fadd := fadd + shiftright(fadd, fshift)
  if (fadd > 0x10000000)
    fadd = shiftright(fadd, 24)
    for j:=0 to 3
      freq[j] = shiftright(freq[j], 24)
  if  (mtfno < 4)
     fc := fadd + freq[mtfno]
  else
     fc := fadd

  // rotate mtf
  k := mtfno
  while k > 3
    mtf[k] := mtf[k-1]
    k := k - 1
  while k > 0 and fc>=freq[k-1]
    mtf[k] := mtf[k-1]
    freq[j] := freq[k-1]
    k := k - 1
  mtf[k] := data[i]
  freq[k] := fc
```

13.2.1.3 Reverse Burrows Wheeler Transform

```
/////// PHASE2 - inverse burrows wheeler transform

assert( markerpos>0 and markerpos<blocksize )

for i := 0 to 255
```

```
    count[i] := 0
  for i := 0 to blocksize-1
    k := data[i]
    posc[i] := k
    if i = markerpos
      posn[i] := 0
    else
      posn[i] := count[k]
      count[k] := count[k] + 1

  last := 1
  for i := 0 to 255
    k := count[i]
    count[i] := last
    last := last + k

  assert( last = blocksize )

  k := 0
  last := blocksize -1
  while last > 0
    last := last - 1
    data[last] := posc[k]
    k := count[posc[k]] + posn[k]

  assert(k = markerpos)

  /////// FIN -  return blocksize-1 decoded bytes
  return data[0 ... blocksize-2]
```

13.2.2 Notes

13.2.2.1 Overview of decoding a block

For each block, one must decode

- the blocksize (with decode_raw)
- the estimation speed FSHIFT=0,1,2 (two bits with the passthru decoder)
- the sequence of symbols representing the Burrows-Wheeler transform of the block. At this point, the sequence of symbols is logically encoded as a sequence of numbers representing the position of each symbol in the MTF array.

Then one must perform the inverse Burrows-Wheeler transform to recover the decoded block.

The following points are significant when recovering the BWT and discussed below:

- The MTF array is reordered after decoding each number.
- The numbers themselves are arithmetically encoded.

13.2.2.2 MTF array reordering:

The MTF array contains 256 bytes initialized with the identity mapping, that is MTF[0]=0, MTF[1]=1, ... MTF[255]=255.

Whenever one decodes a number MTFNO, the corresponding symbol to store in the Burrows-Wheeler buffer is MTF[MTFNO] (except, for the EOB symbol – see 13.2.2.3 Decoding the number MTFNO) and the contents of the MTF array are rotated. The rotation moves the symbol that was at position MTF[MTFNO] to a position M that can be 0, 1, 2, or 3. Meanwhile the symbols MTF[M] to MTF[MTFNO-1] are moved to positions M+1 to MTFNO.

The position M is chosen using an estimate of the frequency of the symbol MTF[MTFNO]. One strives to position the most frequent symbols at the beginning of the MTF array. To that end, one maintains an array FREQ[0..3] that contains numbers representative of the instantaneous frequencies of the symbols MTF[0...3].

Of course this array must also be "rotated" when the rotation of the MTF array affects its first four elements.

Consider the frequency F(T) of a particular symbol S measured after decoding the T-th symbol. Ideally,

$$F(T) = \lambda * F(T-1) + D$$

Where

$0 < \lambda <= 1$. This models how quickly one forgets past information and

D=1 if the T-th symbol is S, and D=0 otherwise. This allows F(T) to grow each time the symbol S occurs

To avoid multiplying all the frequencies by λ, the FREQ array contains instead

$$G(T) = F(T) / \lambda^T$$

It is then easy to see that

$$G(T) = G(T-1) + D / \lambda^T.$$

Therefore we only need to update the G corresponding to the symbol being decoded (i.e. D=1), since the G for the other symbols does not change.

A dedicated variable FADD contains λ^T. Before each rotation we divide FADD by λ^T. This is accomplished by the line

```
FADD = FADD + SHIFTRIGHT(FADD, FSHIFT)
```

The values 0, 1 or 2 of variable FSHIFT correspond the λ = 1/2, 2/3 or 4/5. To avoid overflows we divide everything (FADD and FREQ[0..3]) by 0x10000000 whenever FADD becomes bigger than 0x10000000. This happens rarely enough to take very little time.

The G(T) of the freshly decoded symbol is therefore G(T-1) + FADD. We can only compute this exactly when S is one of the first four symbols of the MTF because we only store FREQ[0..3]. If the decoded number MTFNO is greater than 3, we assume that G(T-1)=0 simply consider G(T)=FADD.

The number M is then chosen to make sure the array FREQ remains sorted in decreasing order after the rotation.

13.2.2.3 Decoding the number MTFNO

Now we can discuss how the numbers MTFNO are stored. There are 262 arithmetic coding contexts. These are initialized to zero at the beginning of the stream decoding process. They should not be reset to zero at the beginning of the block decoding process.

Because the most frequently used symbols should appear near the front of the array, we expect small values for MTFNO (the index into MTF array). By design, the number of bits and the number of contexts required to decode increases for larger values of MTFNO:

A first bit is decoded using context 0, 1 or 2.

Context 0 or 1 are used if the previous MTFNO was 0 or 1. Otherwise context 2 is used, If this bit is set, the new MTFNO is 0.

Otherwise a second bit is decoded using context 3, 4, or 5. Context 3 or 4 are used if the previous MTFNO was 0 or 1. Otherwise context 5 is used. If this bit is set, the new MTFNO is 1

Otherwise a third bit is decoded using context 6. If this bit is set, the new MTFNO is obtained by adding 2 to a 1 bit number decoded with DECODE_BIN using context 7.

Otherwise a fourth bit is decoded using context 8. If this bit is set, the new MTFNO is obtained by adding 4 to a 2 bit number decoded with DECODE_BIN using context 9..11.

And so forth until …

Otherwise a ninth bit is decoded using context 132. If this bit is set, the new MTFNO is obtained by adding 128 to a 7 bit number decoded with DECODE_BIN using context 133..261.

Otherwise the next symbol is the EOB symbol. Since there is only one EOB symbol, we store a zero in the Burrows-Wheeler buffer and record its position in variable MARKERPOS.

13.2.2.4 Inverse Burrows-Wheeler transform

After decoding the BLOCKSIZE symbols composing the Burrows-Wheeler buffer, we need to perform the inverse Burrows-Wheeler transform to recover the BLOCKSIZE-1 decoded bytes followed by the EOB symbol.

To start, we

- copy the buffer into an array POSC[0...BLOCKSIZE-1],
- prepare an array COUNT[0..255] that counts how many occurences of each symbol are found,
- prepare an array POSN[0..BLOCKSIZE-1] that indicates the rank of each occurence of a symbol in the buffer.

Imagine that we are sorting the buffer in symbol order (EOB being the smallest symbol). The buffer would be composed of a single EOB, followed by a run of COUNT[0] symbols 0, followed by a run of COUNT[1] symbols 1, etc.

Using the COUNT array, we compute the position SORTEDPOS[0..255] of each run of symbol in this array.

To perform the inverse Burrows-Wheeler transform, it is now sufficient to follow the thread backwards:

```
k := 0
last := blocksize -1
while last > 0
  last := last - 1
  data[last] := posc[k]
  k := sortedpos[posc[k]] + posn[k]
```

The array DATA[0...BLOCKSIZE-2] then contains the decoded bytes of the block.